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Henry Smith Williams

A
HISTORY OF SCIENCE

BY
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(IN FIVE VOLUMES)

VOLUME I.

THE BEGINNINGS OF SCIENCE

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A HISTORY OF SCIENCE

BOOK I

SHOULD the story that is about to be unfolded be found to lack interest, the writers must stand convicted of unpardonable lack of art. Nothing but dulness in the telling could mar the story, for in itself it is the record of the growth of those ideas that have made our race and its civilization what they are; of ideas instinct with human interest, vital with meaning for our race; fundamental in their influence on human development; part and parcel of the mechanism of human thought on the one hand, and of practical civilization on the other. Such a phrase as "fundamental principles" may seem at first thought a hard saying, but the idea it implies is less repellent than the phrase itself, for the fundamental principles in question are so closely linked with the present interests of every one of us that they lie within the grasp of every average man and woman—nay, of every well-developed boy and girl. These principles are not merely the stepping-stones to culture, the prerequisites of knowledge—

they are, in themselves, an essential part of the knowledge of every cultivated person.

It is our task, not merely to show what these principles are, but to point out how they have been discovered by our predecessors. We shall trace the growth of these ideas from their first vague beginnings. We shall see how vagueness of thought gave way to precision; how a general truth, once grasped and formulated, was found to be a stepping-stone to other truths. We shall see that there are no isolated facts, no isolated principles, in nature; that each part of our story is linked by indissoluble bands with that which goes before, and with that which comes after. For the most part the discovery of this principle or that in a given sequence is no accident. Galileo and Keppler must precede Newton. Cuvier and Lyall must come before Darwin;—which, after all, is no more than saying that in our Temple of Science, as in any other piece of architecture, the foundation must precede the superstructure.

We shall best understand our story of the growth of science if we think of each new principle as a stepping-stone which must fit into its own particular niche; and if we reflect that the entire structure of modern civilization would be different from what it is, and less perfect than it is, had not that particular stepping-stone been found and shaped and placed in position. Taken as a whole, our stepping-stones lead us up and up towards the alluring heights of an acropolis of knowledge, on which stands the Temple of Modern Science. The story of the building of this wonderful structure is in itself fascinating and beautiful.

I

PREHISTORIC SCIENCE

TO speak of a prehistoric science may seem like a contradiction of terms. The word prehistoric seems to imply barbarism, while science, clearly enough, seems the outgrowth of civilization; but rightly considered, there is no contradiction. For, on the one hand, man had ceased to be a barbarian long before the beginning of what we call the historical period; and, on the other hand, science, of a kind, is no less a precursor and a cause of civilization than it is a consequent. To get this clearly in mind, we must ask ourselves: What, then, is science? The word runs glibly enough upon the tongue of our every-day speech, but it is not often, perhaps, that they who use it habitually ask themselves just what it means. Yet the answer is not difficult. A little attention will show that science, as the word is commonly used, implies these things: first, the gathering of knowledge through observation; second, the classification of such knowledge, and through this classification, the elaboration of general ideas or principles. In the familiar definition of Herbert Spencer, science is organized knowledge.

Now it is patent enough, at first glance, that the veriest savage must have been an observer of the phenomena of nature. But it may not be so obvious that he must also have been a classifier of his observations—an organizer of knowledge. Yet the more we consider the case, the more clear it will become that the two methods are too closely linked together to be dissevered. To observe outside phenomena is not more inherent in the nature of the mind than to draw inferences from these phenomena. A deer passing through the forest scents the ground and detects a certain odor. A sequence of ideas is generated in the mind of the deer. Nothing in the deer's experience can produce that odor but a wolf; therefore the scientific inference is drawn that wolves have passed that way. But it is a part of the deer's scientific knowledge, based on previous experience, individual and racial, that wolves are dangerous beasts, and so, combining direct observation in the present with the application of a general principle based on past experience, the deer reaches the very logical conclusion that it may wisely turn about and run in another direction. All this implies, essentially, a comprehension and use of scientific principles; and, strange as it seems to speak of a deer as possessing scientific knowledge, yet there is really no absurdity in the statement. The deer does possess scientific knowledge; knowledge differing in degree only, not in kind, from the knowledge of a Newton. Nor is the animal, within the range of its intelligence, less logical, less scientific in the application of that knowledge, than is the man. The animal that could not make accurate scientific observations of its surroundings, and deduce accurate scientific conclusions from them, would soon pay the penalty of its lack of logic.

What is true of man's precursors in the animal scale is, of course, true in a wider and fuller sense of man himself at the very lowest stage of his development. Ages before the time which the limitations of our knowledge force us to speak of as the dawn of history, man had reached a high stage of development. As a social being, he had developed all the elements of a primitive civilization. If, for convenience of classification, we speak of his state as savage, or barbaric, we use terms which, after all, are relative, and which do not shut off our primitive ancestors from a tolerably close association with our own ideals. We know that, even in the Stone Age, man had learned how to domesticate animals and make them useful to him, and that he had also learned to cultivate the soil. Later on, doubtless by slow and painful stages, he attained those wonderful elements of knowledge that enabled him to smelt metals and to produce implements of bronze, and then of iron. Even in the Stone Age he was a mechanic of marvellous skill, as any one of to-day may satisfy himself by attempting to duplicate such an implement as a chipped arrow-head. And a barbarian who could fashion an axe or a knife of bronze had certainly gone far in his knowledge of scientific principles and their practical application. The practical application was, doubtless, the only thought that our primitive ancestor had in mind; quite probably the question as to principles that might be involved troubled him not at all. Yet, in spite of himself, he knew certain rudimentary principles of science, even though he did not formulate them.

Let us inquire what some of these principles are.

Such an inquiry will, as it were, clear the ground for our structure of science. It will show the plane of knowledge on which historical investigation begins. Incidentally, perhaps, it will reveal to us unsuspected affinities between ourselves and our remote ancestor. Without attempting anything like a full analysis, we may note in passing, not merely what primitive man knew, but what he did not know; that at least a vague notion may be gained of the field for scientific research that lay open for historic man to cultivate.

It must be understood that the knowledge of primitive man, as we are about to outline it, is inferential. We cannot trace the development of these principles, much less can we say who discovered them. Some of them, as already suggested, are man's heritage from non-human ancestors. Others can only have been grasped by him after he had reached a relatively high stage of human development. But all the principles here listed must surely have been parts of our primitive ancestor's knowledge before those earliest days of Egyptian and Babylonian civilization, the records of which constitute our first introduction to the so-called historical period. Taken somewhat in the order of their probable discovery, the scientific ideas of primitive man may be roughly listed as follows:

1. Primitive man must have conceived that the earth is flat and of limitless extent. By this it is not meant to imply that he had a distinct conception of infinity, but, for that matter, it cannot be said that any one to-day has a conception of infinity that could be called definite. But, reasoning from experience

and the reports of travellers, there was nothing to suggest to early man the limit of the earth. He did, indeed, find in his wanderings, that changed climatic conditions barred him from farther progress; but beyond the farthest reaches of his migrations, the seemingly flat land-surfaces and water-surfaces stretched away unbroken and, to all appearances, without end. It would require a reach of the philosophical imagination to conceive a limit to the earth, and while such imaginings may have been current in the prehistoric period, we can have no proof of them, and we may well postpone consideration of man's early dreamings as to the shape of the earth until we enter the historical epoch where we stand on firm ground. pun

2. Primitive man must, from a very early period, have observed that the sun gives heat and light, and that the moon and stars seem to give light only and no heat. It required but a slight extension of this observation to note that the changing phases of the seasons were associated with the seeming approach and recession of the sun. This observation, however, could not have been made until man had migrated from the tropical regions, and had reached a stage of mechanical development enabling him to live in subtropical or temperate zones. Even then it is conceivable that a long period must have elapsed before a direct causal relation was felt to exist between the shifting of the sun and the shifting of the seasons; because, as every one knows, the periods of greatest heat in summer and greatest cold in winter usually come some weeks after the time of the solstices. Yet, the fact that these extremes of temperature are asso-

ciated in some way with the change of the sun's place in the heavens must, in time, have impressed itself upon even a rudimentary intelligence. It is hardly necessary to add that this is not meant to imply any definite knowledge of the real meaning of the seeming oscillations of the sun. We shall see that, even at a relatively late period, the vaguest notions were still in vogue as to the cause of the sun's changes of position.

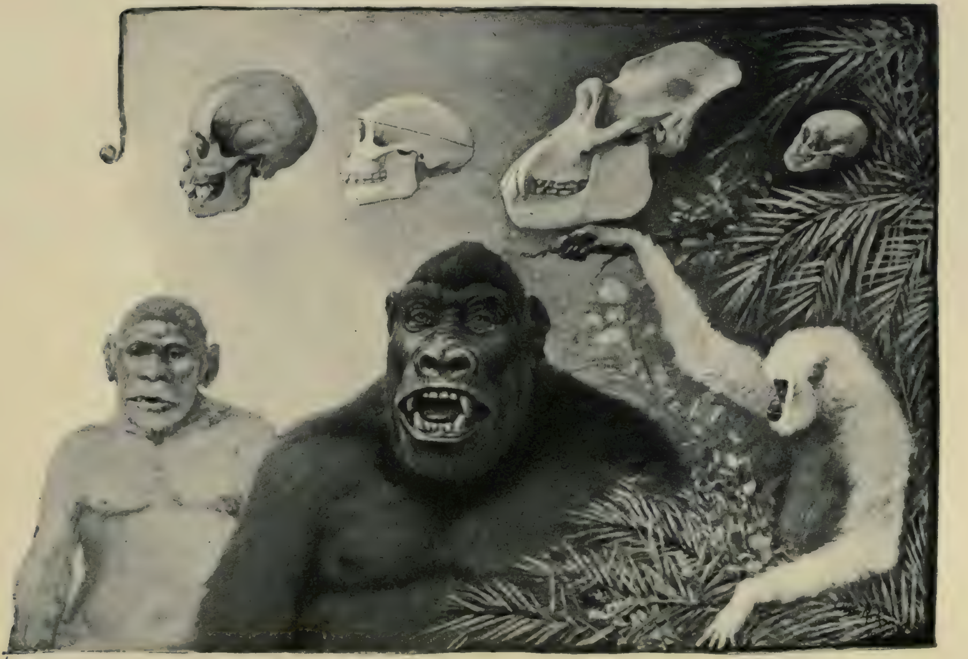
That the sun, moon, and stars move across the heavens must obviously have been among the earliest scientific observations. It must not be inferred, however, that this observation implied a necessary conception of the complete revolution of these bodies about the earth. It is unnecessary to speculate here as to how the primitive intelligence conceived the transfer of the sun from the western to the eastern horizon, to be effected each night, for we shall have occasion to examine some historical speculations regarding this phenomenon. We may assume, however, that the idea of the transfer of the heavenly bodies beneath the earth (whatever the conception as to the form of that body) must early have presented itself.

It required a relatively high development of the observing faculties, yet a development which man must have attained ages before the historical period, to note that the moon has a secondary motion, which leads it to shift its relative position in the heavens, as regards the stars; that the stars themselves, on the other hand, keep a fixed relation as regards one another, with the notable exception of two or three of the most brilliant members of the galaxy, the latter being the bodies which came to be known finally as planets, or wandering stars. The wandering propensities of such brilliant bodies as Jupiter and Venus cannot well have escaped detection. We may safely assume, however, that these anomalous motions of the moon and planets found no explanation that could be called scientific until a relatively late period.

3. Turning from the heavens to the earth, and ignoring such primitive observations as that of the distinction between land and water, we may note that there was one great scientific law which must have forced itself upon the attention of primitive man. This is the law of universal terrestrial gravitation. The word gravitation suggests the name of Newton, and it may excite surprise to hear a knowledge of gravitation ascribed to men who preceded that philosopher by, say, twenty-five or fifty thousand years. Yet the slightest consideration of the facts will make it clear that the great central law that all heavy bodies fall directly towards the earth, cannot have escaped the attention of the most primitive intelligence. The arboreal habits of our primitive ancestors gave opportunities for constant observation of the practicalities of this law. And, so soon as man had developed the mental capacity to formulate ideas, one of the earliest ideas must have been the conception, however vaguely phrased in words, that all unsupported bodies fall towards the earth. The same phenomenon being observed to operate on water-surfaces, and no alteration being observed in its operation in different portions of man's habitat, the most primitive wanderer must have come to have full faith in the universal action of the ob-

served law of gravitation. Indeed, it is inconceivable that he can have imagined a place on the earth where this law does not operate. On the other hand, of course, he never grasped the conception of the operation of this law beyond the close proximity of the earth. To extend the reach of gravitation out to the moon and to the stars, including within its compass every particle of matter in the universe, was the work of Newton, as we shall see in due course. Meantime we shall better understand that work if we recall that the mere local fact of terrestrial gravitation has been the familiar knowledge of all generations of men. It may further help to connect us in sympathy with our primeval ancestor if we recall that in the attempt to explain this fact of terrestrial gravitation Newton made no advance, and we of to-day are scarcely more enlightened than the man of the Stone Age. Like the man of the Stone Age, we know that an arrow shot into the sky falls back to the earth. We can calculate, as he could not do, the arc it will describe and the exact speed of its fall; but as to why it returns to earth at all, the greatest philosopher of to-day is almost as much in the dark as was the first primitive bowman that ever made the experiment.

Other physical facts going to make up an elementary science of mechanics, that were demonstratively known to prehistoric man, were such as these: the rigidity of solids and the mobility of liquids; the fact that changes of temperature transform solids to liquids and *vice versa*—that heat, for example, melts copper and even iron, and that cold congeals water; and the fact that



MAN AND THE ANTHROPOID APES

(A study of the lowest known type of prehistoric man (*Pithecanthropus erectus*), in comparison with the gorilla and the gibbon. At the left is shown an average human skull.)

friction, as illustrated in the rubbing together of two sticks, may produce heat enough to cause a fire. The rationale of this last experiment did not receive an explanation until about the beginning of the nineteenth century of our own era. But the experimental fact was so well known to prehistoric man that he employed this method, as various savage tribes employ it to this day, for the altogether practical purpose of making a fire; just as he employed his practical knowledge of the mutability of solids and liquids in smelting ores, in alloying copper with tin to make bronze, and in casting this alloy in molds to make various implements and weapons. Here, then, were the germs of an elementary science of physics. Meanwhile such observations as that of the solution of salt in water may be considered as giving a first lesson in chemistry, but beyond such altogether rudimentary conceptions chemical knowledge could not have gone—unless, indeed, the practical observation of the effects of fire be included; nor can this well be overlooked, since scarcely another single line of practical observation had a more direct influence in promoting the progress of man towards the heights of civilization.

4. In the field of what we now speak of as biological knowledge, primitive man had obviously the widest opportunity for practical observation. We can hardly doubt that man attained, at an early day, to that conception of identity and of difference which Plato places at the head of his metaphysical system. We shall urge presently that it is precisely such general ideas as these that were man's earliest inductions from observation, and hence that came to seem the most universal and

"innate" ideas of his mentality. It is quite inconceivable, for example, that even the most rudimentary intelligence that could be called human could fail to discriminate between living things and, let us say, the rocks of the earth. The most primitive intelligence, then, must have made a tacit classification of the natural objects about it into the grand divisions of animate and inanimate nature. Doubtless the nascent scientist may have imagined life animating many bodies that we should call inanimate—such as the sun, wandering planets, the winds, and lightning; and, on the other hand, he may quite likely have relegated such objects as trees to the ranks of the non-living; but that he recognized a fundamental distinction between, let us say, a wolf and a granite bowlder we cannot well doubt. A step beyond this—a step, however, that may have required centuries or millenniums in the taking—must have carried man to a plane of intelligence from which a primitive Aristotle or Linnæus was enabled to note differences and resemblances connoting such groups of things as fishes, birds, and furry beasts. This conception, to be sure, is an abstraction of a relatively high order. We know that there are savage races to-day whose language contains no word for such an abstraction as bird or tree. We are bound to believe, then, that there were long ages of human progress during which the highest man had attained no such stage of abstraction; but, on the other hand, it is equally little in question that this degree of mental development had been attained long before the opening of our historical period. The primeval man, then, whose scientific knowledge we are attempting to predicate, had become, through his conception of fishes, birds, and hairy animals as separate classes, a scientific zoologist of relatively high attainments.

In the practical field of medical knowledge, a certain stage of development must have been reached at a very early day. Even animals pick and choose among the vegetables about them, and at times seek out certain herbs quite different from their ordinary food, practising a sort of instinctive therapeutics. The cat's fondness for catnip is a case in point. The most primitive man, then, must have inherited a racial or instinctive knowledge of the medicinal effects of certain herbs; in particular he must have had such elementary knowledge of toxicology as would enable him to avoid eating certain poisonous berries. Perhaps, indeed, we are placing the effect before the cause to some extent; for, after all, the animal system possesses marvellous powers of adaption, and there is perhaps hardly any poisonous vegetable which man might not have learned to eat without deleterious effect, provided the experiment were made gradually. To a certain extent, then, the observed poisonous effects of numerous plants upon the human system are to be explained by the fact that our ancestors have avoided this particular vegetable. Certain fruits and berries might have come to have been a part of man's diet, had they grown in the regions he inhabited at an early day, which now are poisonous to his system. This thought, however, carries us too far afield. For practical purposes, it suffices that certain roots, leaves, and fruits possess principles that are poisonous to the human system, and that unless man had learned in some way to avoid these, our race must have come to disaster. In point of fact, he did learn to avoid them; and such evidence implied, as has been said, an elementary knowledge of toxicology.

Coupled with this knowledge of things dangerous to the human system, there must have grown up, at a very early day, a belief in the remedial character of various vegetables as agents to combat disease. Here, of course, was a rudimentary therapeutics, a crude principle of an empirical art of medicine. As just suggested, the lower order of animals have an instinctive knowledge that enables them to seek out remedial herbs (though we probably exaggerate the extent of this instinctive knowledge); and if this be true, man must have inherited from his prehuman ancestors this instinct along with the others. That he extended this knowledge through observation and practice, and came early to make extensive use of drugs in the treatment of disease, is placed beyond cavil through the observation of the various existing barbaric tribes, nearly all of whom practice elaborate systems of therapeutics. We shall have occasion to see that even within historic times the particular therapeutic measures employed were often crude, and, as we are accustomed to say, unscientific; but even the crudest of them are really based upon scientific principles, inasmuch as their application implies the deduction of principles of action from previous observations. Certain drugs are applied to appease certain symptoms of disease because in the belief of the medicine-man such drugs have proved beneficial in previous similar cases.

All this, however, implies an appreciation of the fact that man is subject to "natural" diseases, and that if these diseases are not combated, death may result. But it should be understood that the earliest man probably had no such conception as this. Throughout all the ages of early development, what we call "natural" disease and "natural" death meant the onslaught of a tangible enemy. A study of this question leads us to some very curious inferences. The more we look into the matter the more the thought forces itself home to us that the idea of natural death, as we now conceive it, came to primitive man as a relatively late scientific induction. This thought seems almost startling, so axiomatic has the conception "man is mortal" come to appear. Yet a study of the ideas of existing savages, combined with our knowledge of the point of view from which historical peoples regard disease, make it more probable that the primitive conception of human life did not include the idea of necessary death. We are told that the Australian savage who falls from a tree and breaks his neck is not regarded as having met a natural death, but as having been the victim of the magical practices of the "medicine-man" of some neighboring tribe. Similarly, we shall find that the Egyptian and the Babylonian of the early historical period conceived illness as being almost invariably the result of the machinations of an enemy. One need but recall the superstitious observances of the Middle Ages, and the yet more recent belief in witchcraft, to realize how generally disease has been personified as a malicious agent invoked by an unfriendly mind. Indeed, the phraseology of our present-day speech is still reminiscent of this; as when, for example, we speak of an "attack of fever," and the like.

When, following out this idea, we picture to ourselves the conditions under which primitive man lived, it will be evident at once how relatively infrequent must have been his observation of what we usually term natural death. His world was a world of strife; he lived by the chase; he saw animals kill one another; he witnessed the death of his own fellows at the hands of enemies. Naturally enough, then, when a member of his family was "struck down" by invisible agents, he ascribed this death also to violence, even though the offensive agent was concealed. Moreover, having very little idea of the lapse of time—being quite unaccustomed, that is, to reckon events from any fixed era—primitive man cannot have gained at once a clear conception of age as applied to his fellows. Until a relatively late stage of development made tribal life possible, it cannot have been usual for man to have knowledge of his grandparents; as a rule he did not know his own parents after he had passed the adolescent stage and had been turned out upon the world to care for himself. If, then, certain of his fellow-beings showed those evidences of infirmity which we ascribe to age, it did not necessarily follow that he saw any association between such infirmities and the length of time which those persons had lived. The very fact that some barbaric nations retain the custom of killing the aged and infirm, in itself suggests the possibility that this custom arose before a clear conception had been attained that such drags upon the community would be removed presently in the natural order of things. To a person who had no clear conception of the lapse of time and no preconception as to the limited period of man's life, the infirmities of age might very naturally be ascribed to the repeated attacks of those inimical powers which were understood sooner or later to carry off most members of the race. And coupled with this thought would go the conception that inasmuch as some people through luck had escaped the vengeance of all their enemies for long periods, these same individuals might continue to escape for indefinite periods of the future. There were no written records to tell primeval man of events of long ago. He lived in the present, and his sweep of ideas scarcely carried him back beyond the limits of his individual memory. But memory is observed to be fallacious. It must early have been noted that some people recalled events which other participants in them had quite forgotten, and it may readily enough have been inferred that those members of the tribe who spoke of events which others could not recall were merely the ones who were gifted with the best memories. If these reached a period when their memories became vague, it did not follow that their recollections had carried them back to the beginnings of their lives. Indeed, it is contrary to all experience to believe that any man remembers all the things he has once known, and the observed fallaciousness and evanescence of memory would thus tend to substantiate rather than to controvert the idea that various members of a tribe had been alive for an indefinite period.

Without further elaborating the argument, it seems a justifiable inference that the first conception primitive man would have of his own life would not include the thought of natural death, but would, conversely, connote the vague conception of endless life. Our own ancestors, a few generations removed, had not got rid of this conception, as the perpetual quest of the spring of eternal youth amply testifies. A naturalist of our own day has suggested that perhaps birds never die except by violence. The thought, then, that man has a term of years beyond which "in the nature of things," as the saying goes, he may not live, would have dawned but gradually upon the developing intelligence of successive generations of men; and we cannot feel sure that he would fully have grasped the conception of a "natural" termination of human life until he had shaken himself free from the idea that disease is always the result of the magic practice of an enemy. Our observation of historical man in antiquity makes it somewhat doubtful whether this conception had been attained before the close of the prehistoric period. If it had, this conception of the mortality of man was one of the most striking scientific inductions to which prehistoric man attained. Incidentally, it may be noted that the conception of eternal life for the human body being a more primitive idea than the conception of natural death, the idea of the immortality of the spirit would be the most natural of conceptions. The immortal spirit, indeed, would be but a correlative of the immortal body, and the idea which we shall see prevalent among the Egyptians that the soul persists only as long as the body is intact—the idea upon which the practice of mummifying the dead depended—finds a ready explanation. But this phase of the subject carries us somewhat afield. For our present purpose it suffices to have pointed out that the conception of man's mortality—a conception which now seems of all others the most natural and "innate"—was in all probability a relatively late scientific induction of our primitive ancestors.

5. Turning from the consideration of the body to its mental complement, we are forced to admit that here, also, our primitive man must have made certain elementary observations that underlie such sciences as psychology, mathematics, and political economy. The elementary emotions associated with hunger and with satiety, with love and with hatred, must have forced themselves upon the earliest intelligence that reached the plane of conscious self-observation. The capacity to count, at least to the number four or five, is within the range of even animal intelligence. Certain savages have gone scarcely farther than this; but our primeval ancestor, who was forging on towards civilization, had learned to count his fingers and toes, and to number objects about him by fives and tens in consequence, before he passed beyond the plane of numerous existing barbarians. How much beyond this he had gone we need not attempt to inquire; but the relatively high development of mathematics in the early historical period suggests that primeval man had attained a not inconsiderable knowledge of numbers. The humdrum vocation of looking after a numerous progeny must have taught the mother the rudiments of addition and subtraction; and the elements of multiplication and division are implied in the capacity to

carry on even the rudest form of barter, such as the various tribes must have practised from an early day.

As to political ideas, even the crudest tribal life was based on certain conceptions of ownership, at least of tribal ownership, and the application of the principle of likeness and difference to which we have already referred. Each tribe, of course, differed in some regard from other tribes, and the recognition of these differences implied in itself a political classification. A certain tribe took possession of a particular hunting-ground, which became, for the time being, its home, and over which it came to exercise certain rights. An invasion of this territory by another tribe might lead to war, and the banding together of the members of the tribe to repel the invader implied both a recognition of communal unity and a species of prejudice in favor of that community that constituted a primitive patriotism. But this unity of action in opposing another tribe would not prevent a certain rivalry of interest between the members of the same tribe, which would show itself more and more prominently as the tribe increased in size. The association of two or more persons implies, always, the ascendency of some and the subordination of others. Leadership and subordination are necessary correlatives of difference of physical and mental endowment, and rivalry between leaders would inevitably lead to the formation of primitive political parties. With the ultimate success and ascendency of one leader, who secures either absolute power or power modified in accordance with the advice of subordinate leaders, we have the germs of an elaborate political system — an embryo science of government.

Meanwhile, the very existence of such a community implies the recognition on the part of its members of certain individual rights, the recognition of which is essential to communal harmony. The right of individual ownership of the various articles and implements of every-day life must be recognized, or all harmony would be at an end. Certain rules of justice—primitive laws—must, by common consent, give protection to the weakest members of the community. Here are the rudiments of a system of ethics. It may seem anomalous to speak of this primitive morality, this early recognition of the principles of right and wrong, as having any relation to science. Yet, rightly considered, there is no incongruity in such a citation. There cannot well be a doubt that the adoption of those broad principles of right and wrong which underlie the entire structure of modern civilization was due to scientific induction,—in other words, to the belief, based on observation and experience, that the principles implied were essential to communal progress. He who has scanned the pageant of history knows how often these principles seem to be absent in the intercourse of men and nations. Yet the ideal is always there as a standard by which all deeds are judged.

It would appear, then, that the entire superstructure of later science had its foundation in the knowledge and practice of prehistoric man. The civilization of the historical period could not have advanced as it has had there not been countless generations of culture back of it. The new principles of science could not have been evolved had there not been great basal principles which ages of unconscious experiment had impressed upon the mind of our race. Due meed of praise must be given, then, to our primitive ancestor for his scientific accomplishments; but justice demands that we should look a little farther and consider the reverse side of the picture. We have had to do, thus far, chiefly with the positive side of accomplishment. We have pointed out what our primitive ancestor knew, intimating, perhaps, the limitations of his knowledge; but we have had little to say of one all-important feature of his scientific theorizing. The feature in question is based on the highly scientific desire and propensity to find explanations for the phenomena of nature. Without such desire no progress could be made. It is, as we have seen, the generalizing from experience that constitutes real scientific progress; and yet, just as most other good things can be overdone, this scientific propensity may be carried to a disastrous excess.

Primeval man did not escape this danger. He observed, he reasoned, he found explanations; but he did not always discriminate as to the logicality of his reasonings. He failed to recognize the limitations of his knowledge. The observed uniformity in the sequence of certain events impressed on his mind the idea of cause and effect. Proximate causes known, he sought remoter causes; childlike, his inquiring mind was always asking, Why? and, childlike, he demanded an explicit answer. If the forces of nature seemed to combat him, if wind and rain opposed his progress and thunder and lightning seemed to menace his existence, he was led irrevocably to think of those human foes who warred with him, and to see, back of the warfare of the elements, an inscrutable malevolent intelligence which took this method to express its displeasure. But every other line of scientific observation leads equally, following back a sequence of events, to seemingly causeless beginnings. Modern science can explain the lightning, as it can explain a great number of the mysteries which the primeval intelligence could not penetrate. But the primordial man could not wait for the revelations of scientific investigation: he must vault at once to a final solution of all scientific problems. He found his solution by peopling the world with invisible forces, anthropomorphic in their conception, like himself in their thought and action, differing only in the limitations of their powers. His own dream-existence gave him seeming proof of the existence of an *alter ego*, a spiritual portion of himself that could dissever itself from his body and wander at will; his scientific inductions seemed to tell him of a world of invisible beings, capable of influencing him for good or ill. From the scientific exercise of his faculties he evolved the all-encompassing generalizations of invisible and all-powerful causes back of the phenomena of nature. These generalizations, early developed and seemingly supported by the observations of countless generations, came to be among the most firmly established scientific inductions of our primeval ancestor. They obtained a hold upon the mentality of our race that led subsequent generations to think of them, sometimes to speak of them, as "innate" ideas. The observations upon which they were based are now, for the most part, susceptible of other interpretations; but the old interpretations have precedent and prejudice back of them, and they represent ideas that are more difficult than almost any others to eradicate. Always, and everywhere, superstitions based upon unwarranted early scientific deductions have been the most implacable foes to the progress of science. Men have built systems of philosophy around their conception of anthropomorphic deities; they have linked to these systems of philosophy the allied conception of the immutability of man's spirit, and they have asked that scientific progress should stop short at the brink of these systems of philosophy and accept their dictates as final. Yet there is not to-day in existence, and there never has been, one jot of scientific evidence for the existence of these intangible anthropomorphic powers back of nature that is not susceptible of scientific challenge and of more logical interpretation. In despite of which the superstitious beliefs are still as firmly fixed in the minds of a large majority of our race as they were in the mind of our prehistoric ancestor. The fact of this baleful heritage must not be forgotten in estimating the debt of gratitude which historic man owes to his barbaric predecessor.

II

EGYPTIAN SCIENCE

IN the previous chapter we have purposely refrained from referring to any particular tribe or race of historical man. Now, however, we are at the beginnings of national existence, and we have to consider the accomplishments of an individual race; or rather, perhaps, of two or more races that occupied successively the same geographical territory. But even now our studies must for a time remain very general; we shall see little or nothing of the deeds of individual scientists in the course of our study of Egyptian culture. We are still, it must be understood, at the beginnings of history; indeed, we must first bridge over the gap from the prehistoric before we may find ourselves fairly on the line of march of historical science.

At the very outset we may well ask what constitutes the distinction between prehistoric and historic epochs —a distinction which has been constantly implied in much that we have said. The reply savors somewhat of vagueness. It is a distinction having to do, not so much with facts of human progress as with our interpretation of these facts. When we speak of the dawn of history we must not be understood to imply that, at the period in question, there was any sudden change in the intellectual status of the human race or in the status of any individual tribe or nation of men. What we mean is that modern knowledge has penetrated the mists of the past for the period we term historical with something more of clearness and precision than it has been able to bring to bear upon yet earlier periods. New accessions of knowledge may thus shift from time to time the bounds of the so-called historical period. The clearest illustration of this is furnished by our interpretation of Egyptian history. Until recently the biblical records of the Hebrew captivity or service, together with the similar account of Josephus, furnished about all that was known of Egyptian history even of so comparatively recent a time as that of Ramses II. (fifteenth century B.C.), and from that period on there was almost a complete gap until the story was taken up by the Greek historians Herodotus and Diodorus. It is true that the king-lists of the Alexandrian historian, Manetho, were all along accessible in somewhat garbled copies. But at best they seemed to supply unintelligible lists of names and dates which no one was disposed to take seriously. That they were, broadly speaking, true historical records, and most important historical records at that, was not recognized by modern scholars until fresh light had been thrown on the subject from altogether new sources.

These new sources of knowledge of ancient history demand a moment's consideration. They are all-important because they have been the means of extending the historical period of Egyptian history (using the word history in the way just explained) by three or four thousand years. As just suggested, that historical period carried the scholarship of the early nineteenth century scarcely beyond the fifteenth century B.C., but to-day's vision extends with tolerable clearness to about the middle of the fifth millennium B.C. This change has been brought about chiefly through study of the Egyptian hieroglyphics. These hieroglyphics constitute, as we now know, a highly developed system of writing; a system that was practised for some thousands of years, but which fell utterly into disuse in the later Roman period, and the knowledge of which passed absolutely from the mind of man. For about two thousand years no one was able to read, with any degree of explicitness, a single character of this strange script, and the idea became prevalent that it did not constitute a real system of writing, but only a more or less barbaric system of religious symbolism. The falsity of this view was shown early in the nineteenth century when Dr. Thomas Young was led, through study of the famous trilingual inscription of the Rosetta stone, to make the first successful attempt at clearing up the mysteries of the hieroglyphics.

This is not the place to tell the story of his fascinating discoveries and those of his successors. That story belongs to nineteenth-century science, not to the science of the Egyptians. Suffice it here that Young gained the first clew to a few of the phonetic values of the Egyptian symbols, and that the work of discovery was carried on and vastly extended by the Frenchman Champollion, a little later, with the result that the firm foundations of the modern science of Egyptology were laid. Subsequently such students' as Rosellini the Italian, Lepsius the German, and Wilkinson the Englishman, entered the field, which in due course was cultivated by De Rougé in France and Birch in England,

and by such distinguished latter-day workers as Chabas, Mariette, Maspero, Amélineau, and De Morgan among the Frenchmen; Professor Petrie and Dr. Budge in England; and Brugsch Pasha and Professor Erman in Germany, not to mention a large coterie of somewhat less familiar names. These men working, some of them in the field of practical exploration, some as students of the Egyptian language and writing, have restored to us a tolerably precise knowledge of the history of Egypt from the time of the first historical king, Mena, whose date is placed at about the middle of the fifth century B.C. We know not merely the names of most of the subsequent rulers, but something of the deeds of many of them; and, what is vastly more important, we know, thanks to the modern interpretation of the old literature, many things concerning the life of the people, and in particular concerning their highest culture, their methods of thought, and their scientific attainments, which might well have been supposed to be past finding out. Nor has modern investigation halted with the time of the first kings; the recent explorations of such archæologists as Amélineau, De Morgan, and Petrie have brought to light numerous remains of what is now spoken of as the predynastic period—a period when the inhabitants of the Nile Valley used implements of chipped stone, when their pottery was made without the use of the potter's wheel, and when they buried their dead in curiously cramped attitudes without attempt at mummification. These aboriginal inhabitants of Egypt cannot perhaps with strict propriety be spoken of as living within the historical period, since we cannot date their relics with any accuracy. But they give us glimpses of the early stages of civilization upon which the Egyptians of the dynastic period were to advance.

It is held that the nascent civilization of these Egyptians of the Neolithic, or late Stone Age, was overthrown by the invading hosts of a more highly civilized race which probably came from the East, and which may have been of a Semitic stock. The presumption is that this invading people brought with it a knowledge of the arts of war and peace, developed or adopted in its old home. The introduction of these arts served to bridge somewhat suddenly, so far as Egypt is concerned, that gap between the prehistoric and the historic stage of culture to which we have all along referred. The essential structure of that bridge, let it now be clearly understood, consisted of a single element. That element is the capacity to make written records: a knowledge of the art of writing. Clearly understood, it is this element of knowledge that forms the line bounding the historical period. Numberless mementos are in existence that tell of the intellectual activities of prehistoric man; such mementos as flint implements, pieces of pottery, and fragments of bone, inscribed with pictures that may fairly be spoken of as works of art; but so long as no written word accompanies these records, so long as no name of king or scribe comes down to us, we feel that these records belong to the domain of archæology rather than to that of history. Yet it must be understood all along that these two domains shade one into the other and, it has already been urged, that the distinction between them is one that pertains rather to modern scholarship than to the development of civilization itself. Bearing this distinction still in mind, and recalling that the historical period, which is to be the field of our observation throughout the rest of our studies, extends for Egypt well back into the fifth millennium B.C., let us briefly review the practical phases of that civilization to which the Egyptian had attained before the beginning of the dynastic period. Since theoretical science is everywhere linked with the mechanical arts, this survey will give us a clear comprehension of the field that lies open for the progress of science in the long stages of historical time upon which we are just entering.

We may pass over such rudimentary advances in the direction of civilization as are implied in the use of articulate language, the application of fire to the uses of man, and the systematic making of dwellings of one sort or another, since all of these are stages of progress that were reached very early in the prehistoric period. What more directly concerns us is to note that a really high stage of mechanical development had been reached before the dawnings of Egyptian history proper. All manner of household utensils were employed; the potter's wheel aided in the construction of a great variety of earthen vessels; weaving had become a fine art, and weapons of bronze, including axes, spears, knives, and arrow-heads, were in constant use. Animals had long been domesticated, in particular the dog, the cat, and the ox; the horse was introduced later from the East. The practical arts of agriculture were practised almost as they are at the present day in Egypt, there being, of course, the same dependence then as now upon the inundations of the Nile.

As to government, the Egyptian of the first dynasty regarded his king as a demi-god to be actually deified after his death, and this point of view was not changed throughout the stages of later Egyptian history. In point of art, marvellous advances upon the skill of the prehistoric man had been made, probably in part under Asiatic influences, and that unique style of stilted yet expressive drawing had come into vogue, which was to be remembered in after times as typically Egyptian. More important than all else, our Egyptian of the earliest historical period was in possession of the art of writing. He had begun to make those specific records which were impossible to the man of the Stone Age, and thus he had entered fully upon the way of historical progress which, as already pointed out, has its very foundation in written records. From now on the deeds of individual kings could find specific record. It began to be possible to fix the chronology of remote events with some accuracy; and with this same fixing of chronologies came the advent of true history. The period which precedes what is usually spoken of as the first dynasty in Egypt is one into which the present-day searcher is still able to see but darkly. The evidence seems to suggest than an invasion of relatively cultured people from the East overthrew, and in time supplanted, the Neolithic civilization of the Nile Valley. It is impossible to date this invasion accurately, but it cannot well have been later than the year 5000 B.C., and it may have been a great many centuries earlier than this. Be the exact dates what they may, we find the Egyptian of the fifth millennium B.C. in full possession of a highly organized civilization.

All subsequent ages have marvelled at the pyramids, some of which date from about the year 4000 B.C., though we may note in passing that these dates must not be taken too literally. The chronology of ancient Egypt cannot as yet be fixed with exact accuracy, but the disagreements between the various students of the subject need give us little concern. For our present purpose it does not in the least matter whether the pyramids were built three thousand or four thousand years before the beginning of our era. It suffices that they date back to a period long antecedent to the beginnings of civilization in Western Europe. They prove that the Egyptian of that early day had attained a knowledge of practical mechanics which, even from the twentieth-century point of view, is not to be spoken of lightly. It has sometimes been suggested that these mighty pyramids, built as they are of great blocks of stone, speak for an almost miraculous knowledge on the part of their builders; but a saner view of the conditions gives no warrant for this thought. Diodorus, the Sicilian, in his famous *World's History*, written about the beginning of our era, explains the building of the pyramids by suggesting that great quantities of earth were piled against the side of the rising structure to form an inclined plane up which the blocks of stone were dragged. He gives us certain figures, based, doubtless, on reports made to him by Egyptian priests, who in turn drew upon the traditions of their country, perhaps even upon written records no longer preserved. He says that one hundred and twenty thousand men were employed in the construction of the largest pyramid, and that, notwithstanding the size of this host of workers, the task occupied twenty years. We must not place too much dependence upon such figures as these, for the ancient historians are notoriously given to exaggeration in recording numbers; yet we need not doubt that the report given by Diodorus is substantially accurate in its main outlines as to the method through which the pyramids were constructed. A host of men putting their added weight and strength to the task, with the aid of ropes, pulleys, rollers, and levers, and utilizing the principle of the inclined plane, could undoubtedly move and elevate and place in position the largest blocks that enter into the pyramids or—what seems even more wonderful — the most gigantic obelisks, without the aid of any other kind of mechanism or of any more occult power. The same hands could, as Diodorus suggests, remove all trace of the débris of construction and leave the pyramids and obelisks standing in weird isolation, as if sprung into being through a miracle.

ASTRONOMICAL SCIENCE

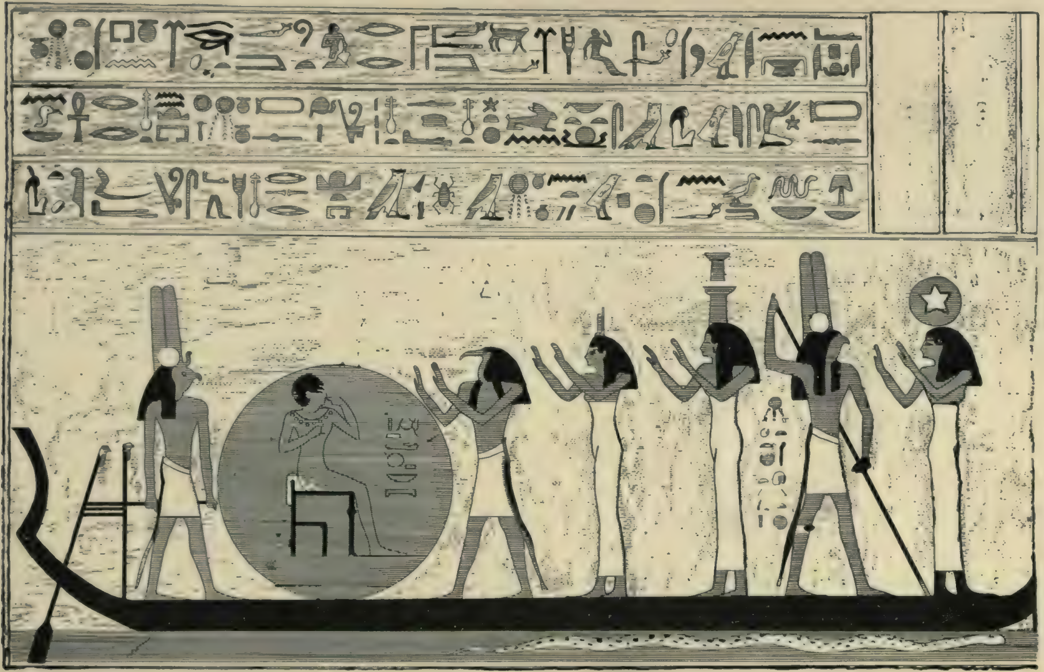
It has been necessary to bear in mind these phases of practical civilization because much that we know of the purely scientific attainments of the Egyptians is based upon modern observation of their pyramids and temples. It was early observed, for example, that the pyramids are obviously oriented as regards the direction in which they face, in strict accordance with some astronomical principle. Early in the nineteenth century the Frenchman Biot made interesting studies in regard to this subject, and a hundred years later, in our own time, Sir Joseph Norman Lockyer, following up the work of various intermediary observers, has given the subject much attention, making it the central theme of his work on *The Dawn of Astronomy*.[1] Lockyer's researches make it clear that in the main the temples of Egypt were oriented with reference to the point at which the sun rises on the day of the summer solstice. The time of the solstice had peculiar interest for the Egyptians, because it corresponded rather closely with the time of the rising of the Nile. The floods of that river appear with very great regularity; the on-rushing tide reaches the region of Heliopolis and Memphis almost precisely on the day of the summer solstice. The time varies at different stages of the river's course, but as the civilization of the early dynasties centred at Memphis, observations made at this place had widest vogue.

Considering the all-essential character of the Nile floods—without which civilization would be impossible in Egypt—it is not strange that the time of their appearance should be taken as marking the beginning of a new year. The fact that their coming coincides with the solstice makes such a division of the calendar perfectly natural. In point of fact, from the earliest periods of which records have come down to us, the new year of the Egyptians dates from the summer solstice. It is certain that from the earliest historical periods the Egyptians were aware of the approximate length of the year. It would be strange were it otherwise, considering the ease with which a record of days could be kept from Nile flood to Nile flood, or from solstice to solstice. But this, of course, applies only to an approximate count. There is some reason to believe that in the earliest period the Egyptians made this count only 360 days. The fact that their year was divided into twelve months of thirty days each lends color to this belief; but, in any event, the mistake was discovered in due time and a partial remedy was applied through the interpolation of a "little month" of five days between the end of the twelfth month and the new year. This nearly but not quite remedied the matter. What it obviously failed to do was to take account of that additional quarter of a day which really rounds out the actual year.

It would have been a vastly convenient thing for humanity had it chanced that the earth had so accommodated its rotary motion with its speed of transit about the sun as to make its annual flight in precisely 360 days. Twelve lunar months of thirty days each would then have coincided exactly with the solar year, and most of the complexities of the calendar, which have so puzzled historical students, would have been avoided; but, on the other hand, perhaps this very simplicity would have proved detrimental to astronomical science by preventing men from searching the heavens as carefully as they have done. Be that as it may, the complexity exists. The actual year of three hundred and sixty-five and (about) one-quarter days cannot be divided evenly into months, and some such expedient as the intercalation of days here and there is essential, else the calendar will become absolutely out of harmony with the seasons.

In the case of the Egyptians, the attempt at adjustment was made, as just noted, by the introduction of the five days, constituting what the Egyptians themselves termed "the five days over and above the year." These so-called epagomenal days were undoubtedly introduced at a very early period. Maspero holds that they were in use before the first Thinite dynasty, citing in evidence the fact that the legend of Osiris explains these days as having been created by the god Thot in order to permit Nuit to give birth to all her children; this expedient being necessary to overcome a ban which had been pronounced against Nuit, according to which she could not give birth to children on any day of the year. But, of course, the five additional days do not suffice fully to rectify the calendar. There remains the additional quarter of a day to be accounted for. This, of course, amounts to a full day every fourth year. We shall see that later Alexandrian science hit upon the expedient of adding a day to every fourth year; an expedient which the Julian calendar adopted and which still gives us our familiar leap-year. But, unfortunately, the ancient Egyptian failed to recognize the need of this additional day, or if he did recognize it he failed to act on his knowledge, and so it happened that, starting somewhere back in the remote past with a new year's day that coincided with the inundation of the Nile, there was a constantly shifting maladjustment of calendar and seasons as time went on.

The Egyptian seasons, it should be explained, were three in number: the season of the inundation, the season of the seed-time, and the season of the harvest; each season being, of course, four months in extent. Originally, as just mentioned, the season of the inun-



THE SUN EMBARKING FOR HIS DAILY JOURNEY THROUGH EGYPT

(Redrawn from Rosellini, *Monumenti del culto*, pl. xxxviii., No. i., taken from one of the scenes represented upon the architraves of the pronaos at Edfû.)

dations began and coincided with the actual time of inundation. The more precise fixing of new year's day was accomplished through observation of the time of the so-called heliacal rising of the dog-star, Sirius, which bore the Egyptian name Sothis. It chances that, as viewed from about the region of Heliopolis, the sun at the time of the summer solstice occupies an apparent position in the heavens close to the dog-star. Now, as is well known, the Egyptians, seeing divinity back of almost every phenomenon of nature, very naturally paid particular reverence to so obviously influential a personage as the sun-god. In particular they thought it fitting to do homage to him just as he was starting out on his tour of Egypt in the morning; and that they might know the precise moment of his coming, the Egyptian astronomer priests, perched on the hill-tops near their temples, were wont to scan the eastern horizon with reference to some star which had been observed to precede the solar luminary. Of course the precession of the equinoxes, due to that axial wobble in which our clumsy earth indulges, would change the apparent position of the fixed stars in reference to the sun, so that the same star could not do service as heliacal messenger indefinitely; but, on the other hand, these changes are so slow that observations by many generations of astronomers would be required to detect the shifting. It is believed by Lockyer, though the evidence is not quite demonstrative, that the astronomical observations of the Egyptians date back to a period when Sothis, the dog-star, was not in close association with the sun on the morning of the summer solstice. Yet, according to the calculations of Biot, the heliacal rising of Sothis at the solstice was noted as early as the year 3285 B.C., and it is certain that this star continued throughout subsequent centuries to keep this position of peculiar prestige. Hence it was that Sothis came to be associated with Isis, one of the most important divinities of Egypt, and that the day in which Sothis was first visible in the morning sky marked the beginning of the new year; that day coinciding, as already noted, with the summer solstice and with the beginning of the Nile flow.

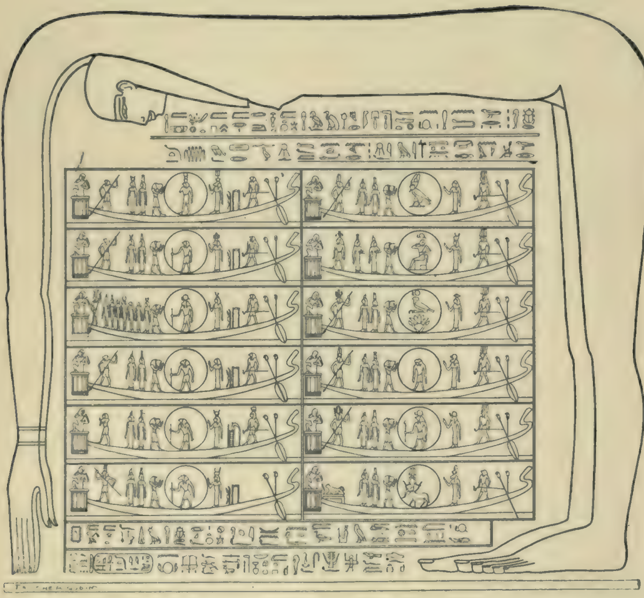
But now for the difficulties introduced by that unreckoned quarter of a day. Obviously with a calendar of 365 days only, at the end of four years, the calendar year, or vague year, as the Egyptians came to call it, had gained by one full day upon the actual solar year—that is to say, the heliacal rising of Sothis, the dog-star, would not occur on new year's day of the faulty calendar, but a day later. And with each succeeding period of four years the day of heliacal rising, which marked the true beginning of the year—and which still, of course, coincided with the inundation—would have fallen another day behind the calendar. In the course of 120 years an entire month would be lost; and in 480 years so great would become the shifting that the seasons would be altogether misplaced; the actual time of inundations corresponding with what the calendar registered as the seed-time, and the actual seed-time in turn corresponding with the harvest-time of the calendar.

At first thought this seems very awkward and confusing, but in all probability the effects were by no means so much so in actual practice. We need go no farther than to our own experience to know that the names of seasons, as of months and days, come to have in the minds of most of us a purely conventional significance. Few of us stop to give a thought to the meaning of the words January, February, etc., except as they connote certain climatic conditions. If, then, our own calendar were so defective that in the course of 120 years the month of February had shifted back to occupy the position of the original January, the change would have been so gradual, covering the period of two life-times or of four or five average generations, that it might well escape general observation.

Each succeeding generation of Egyptians, then, may not improbably have associated the names of the seasons with the contemporary climatic conditions, troubling themselves little with the thought that in an earlier age the climatic conditions for each period of the calendar were quite different. We cannot well suppose, however, that the astronomer priests were oblivious to the true state of things. Upon them devolved the duty of predicting the time of the Nile flood; a duty they were enabled to perform without difficulty through observation of the rising of the solstitial sun and its Sothic messenger. To these observers it must finally have been apparent that the shifting of the seasons was at the rate of one day in four years; this known, it required no great mathematical skill to compute that this shifting would finally effect a complete circuit of the calendar, so that after (4 × 365 =) 1460 years the first day of the calendar year would again coincide with the heliacal rising of Sothis and with the coming of the Nile flood. In other words, 1461 vague years or Egyptian calendar years of 365 days each correspond to 1460 actual solar years of 365¼ days each. This period, measured thus by the heliacal rising of Sothis, is spoken of as the Sothic cycle.

To us who are trained from childhood to understand that the year consists of (approximately) 365¼ days, and to know that the calendar may be regulated approximately by the introduction of an extra day every fourth year, this recognition of the Sothic cycle seems simple enough. Yet if the average man of us will reflect how little he knows, of his own knowledge, of the exact length of the year, it will soon become evident that the appreciation of the faults of the calendar and the knowledge of its periodical adjustment constituted a relatively high development of scientific knowledge on the part of the Egyptian astronomer. It may be added that various efforts to reform the calendar were made by the ancient Egyptians, but that they cannot be credited with a satisfactory solution of the problem; for, of course, the Alexandrian scientists of the Ptolemaic period (whose work we shall have occasion to review presently) were not Egyptians in any proper sense of the word, but Greeks.

Since so much of the time of the astronomer priests was devoted to observation of the heavenly bodies, it is not surprising that they should have mapped out the apparent course of the moon and the visible planets in their nightly tour of the heavens, and that they should have divided the stars of the firmament into more or less arbitrary groups or constellations. That they did



TWELVE STAGES IN THE LIFE OF THE SUN AND ITS TWELVE FORMS THROUGHOUT THE DAY

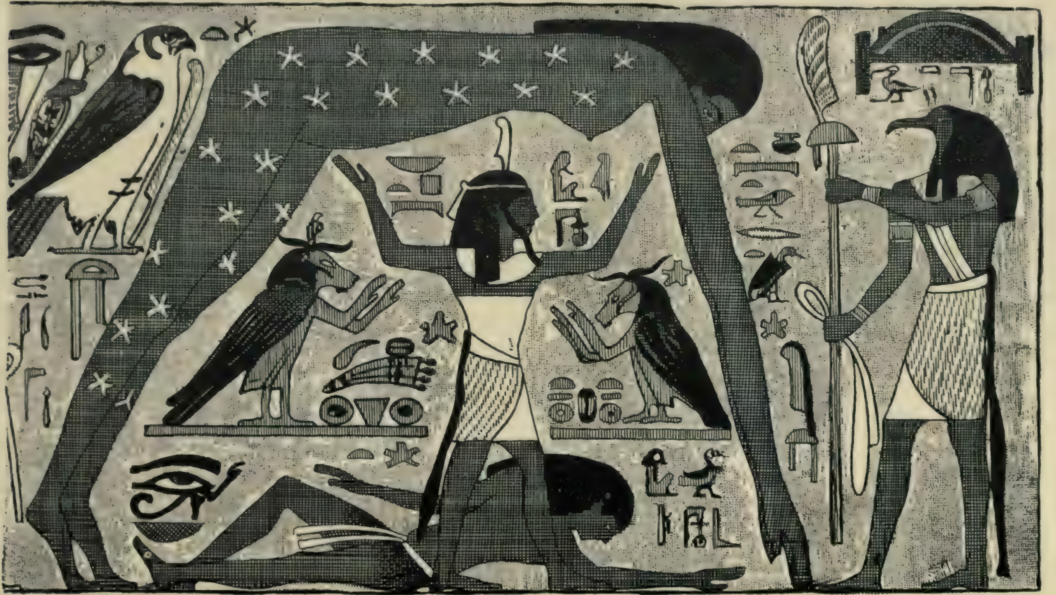
(From a drawing by Faucher-Gudin in Maspero's *Dawn of Civilization*, from the ceiling of the Hall of the New Year at Edfû.)

so is evidenced by various sculptured representations of constellations corresponding to signs of the zodiac which still ornament the ceilings of various ancient temples. Unfortunately the decorative sense, which was always predominant with the Egyptian sculptor, led him to take various liberties with the distribution of figures in these representations of the constellations, so that the inferences drawn from them as to the exact map of the heavens as the Egyptians conceived it cannot be fully relied upon. It appears, however, that the Egyptian astronomer divided the zodiac into twenty-four decani, or constellations. The arbitrary groupings of figures, with the aid of which these are delineated, bear a close resemblance to the equally arbitrary outlines which we are still accustomed to use for the same purpose.

IDEAS OF COSMOLOGY

In viewing this astronomical system of the Egyptians one cannot avoid the question as to just what interpretation was placed upon it as regards the actual mechanical structure of the universe. A proximal answer to the question is supplied us with a good deal of clearness. It appears that the Egyptian conceived the sky as a sort of tangible or material roof placed above the world, and supported at each of its four corners by a column or pillar, which was later on conceived as a great mountain. The earth itself was conceived to be a rectangular box, longer from north to south than from east to west; the upper surface of this box, upon which man lived, being slightly concave and having, of course, the valley of the Nile as its centre. The pillars of support were situated at the points of the compass; the northern one being located beyond the Mediterranean Sea; the southern one away beyond the habitable regions towards the source of the Nile, and the eastern and western ones in equally inaccessible regions. Circling about the southern side of the world was a great river suspended in mid-air on something comparable to mountain cliffs; on which river the sun-god made his daily course in a boat, fighting day by day his ever-recurring battle against Set, the demon of darkness. The wide channel of this river enabled the sun-god to alter his course from time to time, as he is observed to do; in winter directing his bark towards the farther bank of the channel; in summer gliding close to the nearer bank. As to the stars, they were similar lights, suspended from the vault of the heaven; but just how their observed motion of translation across the heavens was explained is not apparent. It is more than probable that no one explanation was universally accepted.

In explaining the origin of this mechanism of the heavens, the Egyptian imagination ran riot. Each separate part of Egypt had its own hierarchy of gods, and more or less its own explanations of cosmogony. There does not appear to have been any one central story of creation that found universal acceptance, any more than there was one specific deity everywhere recognized as supreme among the gods. Perhaps the most interesting of the cosmogonic myths was that which conceived that Nuit, the goddess of night, had been torn from the arms of her husband, Sibû the earth-god, and elevated to the sky despite her protests and



SHU SEPARATING SIBÛ AND NUIT

(From a drawing by Faucher-Gudin in Maspero's *Dawn of Civilization*, from a painting on a mummy-case in the Turin Museum. See p. 42.)

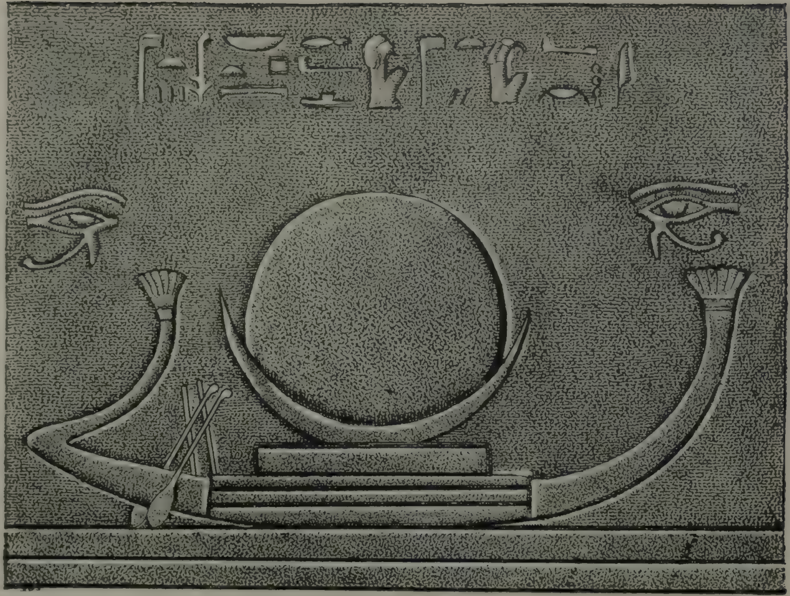
her husband's struggles, there to remain supported by her four limbs, which became metamorphosed into the pillars, or mountains, already mentioned. The forcible elevation of Nuit had been effected on the day of creation by a new god, Shu, who came forth from the primeval waters. A painting on the mummy case of one Betuhamon, now in the Turin Museum, illustrates, in the graphic manner so characteristic of the Egyptians, this act of creation. As Maspero[2] points out, the struggle of Sibû resulted in contorted attitudes to which the irregularities of the earth's surface are to be ascribed.

In contemplating such a scheme of celestial mechanics as that just outlined, one cannot avoid raising the question as to just the degree of literalness which the Egyptians themselves put upon it. We know how essentially eye-minded the Egyptian was, to use a modern psychological phrase—that is to say, how essential to him it seemed that all his conceptions should be visualized. The evidences of this are everywhere: all his gods were made tangible; he believed in the immortality of the soul, yet he could not conceive of such immortality except in association with an immortal body; he must mummify the body of the dead, else, as he firmly believed, the dissolution of the spirit would take place along with the dissolution of the body itself. His world was peopled everywhere with spirits, but they were spirits associated always with corporeal bodies; his gods found lodgment in sun and moon and stars; in earth and water; in the bodies of reptiles and birds and mammals. He worshipped all of these things: the sun, the moon, water, earth, the spirit of the Nile, the ibis, the cat, the ram, and apis the bull; but, so far as we can judge, his imagination did not reach to the idea of an absolutely incorporeal deity. Similarly his conception of the mechanism of the heavens must be a tangibly mechanical one. He must think of the starry firmament as a substantial entity which could not defy the law of gravitation, and which, therefore, must have the same manner of support as is required by the roof of a house or temple. We know that this idea of the materiality of the firmament found elaborate expression in those later cosmological guesses which were to dominate the thought of Europe until the time of Newton. We need not doubt, therefore, that for the Egyptian this solid vault of the heavens had a very real existence. If now and then some dreamer conceived the great bodies of the firmament as floating in a less material plenum—and such iconoclastic dreamers there are in all ages—no record of his musings has come down to us, and we must freely admit that if such thoughts existed they were alien to the character of the Egyptian mind as a whole.

While the Egyptians conceived the heavenly bodies as the abiding-place of various of their deities, it does not appear that they practised astrology in the later acceptance of that word. This is the more remarkable since the conception of lucky and unlucky days was carried by the Egyptians to the extremes of absurdity. "One day was lucky or unlucky," says Erman,[3] "according as a good or bad mythological incident took place on that day. For instance, the 1st of Mechir, on which day the sky was raised, and the 27th of Athyr, when Horus and Set concluded peace together and divided the world between them, were lucky days; on the other hand, the 14th of Tybi, on which Isis and Nephthys mourned for Osiris, was an unlucky day. With the unlucky days, which, fortunately, were less in number than the lucky days, they distinguished different degrees of ill-luck. Some were very unlucky, others only threatened ill-luck, and many, like the 17th and the 27th Choiakh, were partly good and partly bad according to the time of day. Lucky days might, as a rule, be disregarded. At most it might be as well to visit some specially renowned temple, or to 'celebrate a joyful day at home,' but no particular precautions were really necessary; and, above all, it was said, 'what thou also seest on the day is lucky.' It was quite otherwise with the unlucky and dangerous days, which imposed so many and such great limitations on people that those who wished to be prudent were always obliged to bear them in mind when determining on any course of action. Certain conditions were easy to carry out. Music and singing were to be avoided on the 14th Tybi, the day of the mourning of Osiris, and no one was allowed to wash on the 16th Tybi; whilst the name of Set might not be pronounced on the 24th of Pharmuthi. Fish was forbidden on certain days; and what was still more difficult in a country so rich in mice, on the 12th of Tybi no mouse might be seen. The most tiresome prohibitions, however, were those which occurred not infrequently, namely, those concerning work and going out: for instance, four times in Paophi the people had to 'do nothing at all,' and five times to sit the whole day or half the day in the house; and the same rule had to be observed each month. It was impossible to rejoice if a child was born on the 23d of Thoth; the parents knew it could not live. Those born on the 20th of Choiakh would become blind, and those born on the 3d of Choiakh, deaf."

CHARMS AND INCANTATIONS

Where such conceptions as these pertained, it goes without saying that charms and incantations intended to break the spell of the unlucky omens were equally prevalent. Such incantations consisted usually of the recitation of certain phrases based originally, it would appear, upon incidents in the history of the gods. The words which the god had spoken in connection with some lucky incident would, it was thought, prove effective now in bringing good luck to the human supplicant—that is to say, the magician hoped through repeating the words of the god to exercise the magic power of the god. It was even possible, with the aid of the magical observances, partly to balk fate itself. Thus the person predestined through birth on an unlucky day to die of a serpent bite might postpone the time of this fateful visitation to extreme old age. The like uncertainty attached to those spells which one person was supposed to be able to exercise over another. It was held, for example, that if something belonging to an individual, such as a lock of hair or a paring of the nails, could be secured and incorporated in a waxen figure, this figure would be intimately associated with the personality of that individual. An enemy might thus secure occult power over one; any indignity practised upon the waxen figure would result in like injury



THE SELF-PROPELLING BOAT CONTAINING THE SUN, UNDER THE PROTECTION OF THE TWO EYES

(Redrawn from Maspero's *Dawn of Civilization.*)

to its human prototype. If the figure were bruised or beaten, some accident would overtake its double; if the image were placed over a fire, the human being would fall into a fever, and so on. But, of course, such mysterious evils as these would be met and combated by equally mysterious processes; and so it was that the entire art of medicine was closely linked with magical practices. It was not, indeed, held, according to Maspero, that the magical spells of enemies were the sole sources of human ailments, but one could never be sure to what extent such spells entered into the affliction; and so closely were the human activities associated in the mind of the Egyptian with one form or another of occult influences that purely physical conditions were at a discount. In the later times, at any rate, the physician was usually a priest, and there was a close association between the material and spiritual phases of therapeutics. Erman[4] tells us that the following formula had to be recited at the preparation of all medicaments: "That Isis might make free, make free. That Isis might make Horus free from all evil that his brother Set had done to him when he slew his father, Osiris. O Isis, great enchantress, free me, release me from all evil red things, from the fever of the god, and the fever of the goddess, from death and death from pain, and the pain which comes over me; as thou hast freed, as thou hast released thy son Horus, whilst I enter into the fire and come forth from the water," etc. Again, when the invalid took the medicine, an incantation had to be said which began thus: "Come remedy, come drive it out of my heart, out of these limbs strong in magic power with the remedy." He adds: "There may have been a few rationalists amongst the Egyptian doctors, for the number of magic formulæ varies much in the different books. The book that we have specially taken for a foundation for this account of Egyptian medicine—the great papyrus of the eighteenth dynasty edited by Ebers[5]—contains, for instance, far fewer exorcisms than some later writings with similar contents, probably because the doctor who compiled this book of recipes from older sources had very little liking for magic."

It must be understood, however—indeed, what has just been said implies as much—that the physician by no means relied upon incantations alone; on the contrary, he equipped himself with an astonishing variety of medicaments. He had a particular fondness for what the modern physician speaks of as a "shot-gun" prescription—one containing a great variety of ingredients. Not only did herbs of many kinds enter into this, but such substances as lizard's blood, the teeth of swine, putrid meat, the moisture from pigs' ears, boiled horn, and numerous other even more repellent ingredients. Whoever is familiar with the formulæ employed by European physicians even so recently as the eighteenth century will note a striking similarity here. Erman points out that the modern Egyptian even of this day holds closely to many of the practices of his remote ancestor. In particular, the efficacy of the beetle as a medicinal agent has stood the test of ages of practice. "Against all kinds of witchcraft," says an ancient formula, "a great scarabæus beetle; cut off his head and wings, boil him; put him in oil and lay him out; then cook his head and wings, put them in snake fat, boil, and let the patient drink the mixture." The modern Egyptian, says Erman, uses almost precisely the same recipe, except that the snake fat is replaced by modern oil.

In evidence of the importance which was attached to practical medicine in the Egypt of an early day, the names of several physicians have come down to us from an age which has preserved very few names indeed, save those of kings. In reference to this Erman says[6]: "We still know the names of some of the early body physicians of this time; Sechmetna'eonch, 'chief physician of the Pharaoh,' and Nesmenan his chief, the 'superintendent of the physicians of the Pharaoh.' The priests also of the lioness-headed goddess Sechmet seem to have been famed for their medical wisdom, whilst the son of this goddess, the demi-god Imhôtep, was in later times considered to be the creator of medical knowledge. These ancient doctors of the New Empire do not seem to have improved upon the older conceptions about the construction of the human body."

As to the actual scientific attainments of the Egyptian physician, it is difficult to speak with precision. Despite the cumbersome formulæ and the grotesque incantations, we need not doubt that a certain practical value attended his therapeutics. He practised almost pure empiricism, however, and certainly it must have been almost impossible to determine which ones, if any, of the numerous ingredients of the prescription had real efficacy.

The practical anatomical knowledge of the physician, there is every reason to believe, was extremely limited. At first thought it might seem that the practice of embalming would have led to the custom of dissecting human bodies, and that the Egyptians, as a result of this, would have excelled in the knowledge of anatomy. But the actual results were rather the reverse of this. Embalming the dead, it must be recalled, was a purely religious observance. It took place under the superintendence of the priests, but so great was the reverence for the human body that the priests themselves were not permitted to make the abdominal incision which was a necessary preliminary of the process. This incision, as we are informed by both Herodotus[7] and Diodorus[8], was made by a special officer, whose status, if we may believe the explicit statement of Diodorus, was quite comparable to that of the modern hangman. The paraschistas, as he was called, having performed his necessary but obnoxious function, with the aid of a sharp Ethiopian stone, retired hastily, leaving the remaining processes to the priests. These, however, confined their observations to the abdominal viscera; under no consideration did they make other incisions in the body. It follows, therefore, that their opportunity for anatomical observations was most limited.

Since even the necessary mutilation inflicted on the corpse was regarded with such horror, it follows that anything in the way of dissection for a less sacred purpose was absolutely prohibited. Probably the same prohibition extended to a large number of animals, since most of these were held sacred in one part of Egypt or another. Moreover, there is nothing in what we know of the Egyptian mind to suggest the probability that any Egyptian physician would make extensive anatomical observations for the love of pure knowledge. All Egyptian science is eminently practical. If we think of the Egyptian as mysterious, it is because of the superstitious observances that we everywhere associate with his daily acts; but these, as we have already tried to make clear, were really based on scientific observations of a kind, and the attempt at true inferences from these observations. But whether or not the Egyptian physician desired anatomical knowledge, the results of his inquiries were certainly most meagre. The essentials of his system had to do with a series of vessels, alleged to be twenty-two or twenty-four in number, which penetrated the head and were distributed in pairs to the various members of the body, and which were vaguely thought of as carriers of water, air, excretory fluids, etc. Yet back of this vagueness, as must not be overlooked, there was an all-essential recognition of the heart as the central vascular organ. The heart is called the beginning of all the members. Its vessels, we are told, "lead to all the members; whether the doctor lays his finger on the forehead, on the back of the head, on the hands, on the place of the stomach (?), on the arms, or on the feet, everywhere he meets with the heart, because its vessels lead to all the members."[9] This recognition of the pulse must be credited to the Egyptian physician as a piece of practical knowledge, in some measure off-setting the vagueness of his anatomical theories.

ABSTRACT SCIENCE

But, indeed, practical knowledge was, as has been said over and over, the essential characteristic of Egyptian science. Yet another illustration of this is furnished us if we turn to the more abstract departments of thought and inquire what were the Egyptian attempts in such a field as mathematics. The answer does not tend greatly to increase our admiration for the Egyptian mind. We are led to see, indeed, that the Egyptian merchant was able to perform all the computations necessary to his craft, but we are forced to conclude that the knowledge of numbers scarcely extended beyond this, and that even here the methods of reckoning were tedious and cumbersome. Our knowledge of the subject rests largely upon the so-called papyrus Rhind,[10] which is a sort of mythological hand-book of the ancient Egyptians. Analyzing this document, Professor Erman concludes that the knowledge of the Egyptians was adequate to all practical requirements. Their mathematics taught them "how in the exchange of bread for beer the respective value was to be determined when converted into a quantity of corn; how to reckon the size of a field; how to determine how a given quantity of corn would go into a granary of a certain size," and like every-day problems. Yet they were obliged to make some of their simple computations in a very roundabout way. It would appear, for example, that their mental arithmetic did not enable them to multiply by a number larger than two, and that they did not reach a clear conception of complex fractional numbers. They did, indeed, recognize that each part of an object divided into 10 pieces became $\frac{1}{10}$ of that object; they even grasped the idea of $\frac{2}{3}$, this being a conception easily visualized; but they apparently did not visualize such a conception as $\frac{8}{10}$, except in the crude form of $\frac{1}{10}$ plus $\frac{1}{10}$ plus $\frac{1}{10}$. Their entire idea of division seems defective. They viewed the subject from the more elementary stand-point of multiplication. Thus, in order to find out how many times 7 is contained in 77, an existing example shows that the numbers representing 1 times 7, 2 times 7, 4 times 7, 8 times 7 were set down successively and various experimental additions made to find out which sets of these numbers aggregated 77.

—1	7
—2	14
4	28
—8	56

A line before the first, second, and fourth of these numbers indicated that it is necessary to multiply 7 by 1 plus 2 plus 8—that is, by 11, in order to obtain 77; that is to say, 7 goes 11 times in 77. All this seems very cumbersome indeed, yet we must not overlook the fact that the process which goes on in our own minds in performing such a problem as this is precisely similar, except that we have learned to slur over certain of the intermediate steps with the aid of a memorized multiplication table. In the last analysis, division is only the obverse side of multiplication, and any one who has not learned his multiplication table is reduced to some such expedient as that of the Egyptian. Indeed, whenever we pass beyond the range of our memorized multiplication table—which for most of us ends with the twelves—the experimental character of the trial multiplication through which division is finally effected does not so greatly differ from the experimental efforts which the Egyptian was obliged to apply to smaller numbers.

Despite his defective comprehension of fractions, the Egyptian was able to work out problems of relative complexity; for example, he could determine the answer of such a problem as this: a number together with its fifth part makes 21; what is the number? The process by which the Egyptian solved this problem seems very cumbersome to any one for whom a rudimentary knowledge of algebra makes it simple, yet the method which we employ differs only in that we are enabled, thanks to our hypothetical x, to make a short cut, and the essential fact must not be overlooked that the Egyptian reached a correct solution of the problem. With all due desire to give credit, however, the fact remains that the Egyptian was but a crude mathematician. Here, as elsewhere, it is impossible to admire him for any high development of theoretical science. First, last, and all the time, he was practical, and there is nothing to show that the thought of science for its own sake, for the mere love of knowing, ever entered his head.

In general, then, we must admit that the Egyptian had not progressed far in the hard way of abstract thinking. He worshipped everything about him because he feared the result of failing to do so. He embalmed the dead lest the spirit of the neglected one might come to torment him. Eye-minded as he was, he came to have an artistic sense, to love decorative effects. But he let these always take precedence over his sense of truth; as, for example, when he modified his lists of kings at Abydos to fit the space which the architect had left to be filled; he had no historical sense to show to him that truth should take precedence over mere decoration. And everywhere he lived in the same happy-go-lucky way. He loved personal ease, the pleasures of the table, the luxuries of life, games, recreations, festivals. He took no heed for the morrow, except as the morrow might minister to his personal needs. Essentially a sensual being, he scarcely conceived the meaning of the intellectual life in the modern sense of the term. He had perforce learned some things about astronomy, because these were necessary to his worship of the gods; about practical medicine, because this ministered to his material needs; about practical arithmetic, because this aided him in every-day affairs. The bare rudiments of an historical science may be said to be crudely outlined in his defective lists of kings. But beyond this he did not go. Science as science, and for its own sake, was unknown to him. He had gods for all material functions, and festivals in honor of every god; but there was no goddess of mere wisdom in his pantheon. The conception of Minerva was reserved for the creative genius of another people.

III

SCIENCE OF BABYLONIA AND ASSYRIA

THROUGHOUT classical antiquity Egyptian science was famous. We know that Plato spent some years in Egypt in the hope of penetrating the alleged mysteries of its fabled learning; and the story of the Egyptian priest who patronizingly assured Solon that the Greeks were but babes was quoted everywhere without disapproval. Even so late as the time of Augustus, we find Diodorus, the Sicilian, looking back with veneration upon the Oriental learning, to which Pliny also refers with unbounded respect. From what we have seen of Egyptian science, all this furnishes us with a somewhat striking commentary upon the attainments of the Greeks and Romans themselves. To refer at length to this would be to anticipate our purpose; what now concerns us is to recall that all along there was another nation, or group of nations, that disputed the palm for scientific attainments. This group of nations found a home in the valley of the Tigris and Euphrates. Their land was named Mesopotamia by the Greeks, because a large part of it lay between the two rivers just mentioned. The peoples themselves are familiar to every one as the Babylonians and the Assyrians. These peoples were of Semitic stock—allied, therefore, to the ancient Hebrews and Phœnicians and of the same racial stem with the Arameans and Arabs.

The great capital of the Babylonians during the later period of their history was the famed city of Babylon itself; the most famous capital of the Assyrians was Nineveh, that city to which, as every Bible-student will recall, the prophet Jonah was journeying when he had a much-exploited experience, the record of which forms no part of scientific annals. It was the kings of Assyria, issuing from their palaces in Nineveh, who dominated the civilization of Western Asia during the heyday of Hebrew history, and whose deeds are so frequently mentioned in the Hebrew chronicles. Later on, in the year 606 B.C., Nineveh was overthrown by the Medes[1] and Babylonians. The famous city was completely destroyed, never to be rebuilt. Babylon, however, though conquered subsequently by Cyrus and held in subjection by Darius,[2] the Persian kings, continued to hold sway as a great world-capital for some centuries. The last great historical event that occurred within its walls was the death of Alexander the Great, which took place there in the year 322 B.C.

In the time of Herodotus the fame of Babylon was at its height, and the father of history has left us a most entertaining account of what he saw when he visited the wonderful capital. Unfortunately, Herodotus was not a scholar in the proper acceptance of the term. He probably had no inkling of the Babylonian language, so the voluminous records of its literature were entirely shut off from his observation. He therefore enlightens us but little regarding the science of the Babylonians, though his observations on their practical civilization give us incidental references of no small importance. Somewhat more detailed references to the scientific attainments of the Babylonians are found in the fragments that have come down to us of the writings of the great Babylonian historian, Berosus,[3] who was born in Babylon about 330 B.C., and who was, therefore, a contemporary of Alexander the Great. But the writings of Berosus also, or at least such parts of them as have come down to us, leave very much to be desired in point of explicitness. They give some glimpses of Babylonian history, and they detail at some length the strange mythical tales of creation that entered into the Babylonian conception of cosmogony—details which find their counterpart in the allied recitals of the Hebrews. But taken all in all, the glimpses of the actual state of Chaldean[4] learning, as it was commonly called, amounted to scarcely more than vague wonder-tales. No one really knew just what interpretation to put upon these tales until the explorers of the nineteenth century had excavated the ruins of the Babylonian and Assyrian cities, bringing to light the relics of their wonderful civilization. But these relics fortunately included vast numbers of written documents, inscribed on tablets, prisms, and cylinders of terra-cotta. When nineteenth-century scholarship had penetrated the mysteries of the strange script, and ferreted out the secrets of an unknown tongue, the world at last was in possession of authentic records by which the traditions regarding the Babylonians and Assyrians could be tested. Thanks to these materials, a new science commonly spoken of as Assyriology came into being, and a most important chapter of human history was brought to light. It became apparent that the Greek ideas concerning Mesopotamia, though vague in the extreme, were founded on fact. No one any longer questions that the Mesopotamian civilization was fully on a par with that of Egypt; indeed, it is rather held that superiority lay with the Asiatics. Certainly, in point of purely scientific attainments, the Babylonians passed somewhat beyond their Egyptian competitors. All the evidence seems to suggest also that the Babylonian civilization was even more ancient than that of Egypt. The precise dates are here in dispute; nor for our present purpose need they greatly concern us. But the Assyrio-Babylonian records have much greater historical accuracy as regards matters of chronology than have the Egyptian, and it is believed that our knowledge of the early Babylonian history is carried back, with some certainty, to King Sargon of Agade,[5] for whom the date 3800 B.C. is generally accepted; while somewhat vaguer records give us glimpses of periods as remote as the sixth, perhaps even the seventh or eighth millenniums before our era.

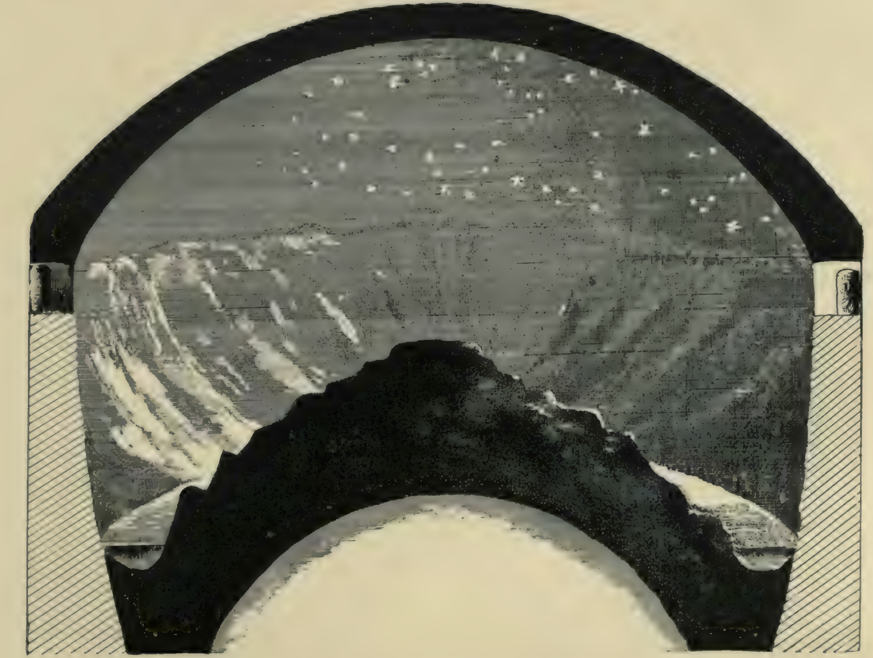
At a very early period Babylon itself was not a capital and Nineveh had not come into existence. The important cities, such as Nippur and Shirpurla, were situated farther to the south. It is on the site of these cities that the recent excavations have been made, such as those of the University of Pennsylvania expeditions at Nippur,[6] which are giving us glimpses into remoter recesses of the historical period.

Even if we disregard the more problematical early dates, we are still concerned with the records of a civilization extending unbroken throughout a period of about four thousand years; the actual period is in all probability twice or thrice that. Naturally enough, the current of history is not an unbroken stream throughout this long epoch. It appears that at least two utterly different ethnic elements are involved. A preponderance of evidence seems to show that the earliest civilized inhabitants of Mesopotamia were not Semitic, but an alien race, which is now commonly spoken of as Sumerian. This people, of whom we catch glimpses chiefly through the records of its successors, appears to have been subjugated or overthrown by Semitic invaders, who, coming perhaps from Arabia (their origin is in dispute), took possession of the region of the Tigris and Euphrates, learned from the Sumerians many of the useful arts, and, partly perhaps because of their mixed lineage, were enabled to develop the most wonderful civilization of antiquity. Could we analyze the details of this civilization from its earliest to its latest period we should of course find the same changes which always attend racial progress and decay. We should then be able, no doubt, to speak of certain golden epochs and their periods of decline. To a certain meagre extent we are able to do this now. We know, for example, that King Khammurabi, who lived about 2200 B.C., was a great law-giver, the ancient prototype of Justinian; and the epochs of such Assyrian kings as Sargon II., Asshurnazirpal, Sennacherib, and Asshurbanapal stand out with much distinctness. Yet, as a whole, the record does not enable us to trace with clearness the progress of scientific thought. At best we can gain fewer glimpses in this direction than in almost any other, for it is the record of war and conquest rather than of the peaceful arts that commanded the attention of the ancient scribe. So in dealing with the scientific achievements of these peoples, we shall perforce consider their varied civilizations as a unity, and attempt, as best we may, to summarize their achievements as a whole. For the most part, we shall not attempt to discriminate as to what share in the final product was due to Sumerian, what to Babylonian, and what to Assyrian. We shall speak of Babylonian science as including all these elements; and drawing our information chiefly from the relatively late Assyrian and Babylonian sources, which, therefore, represent the culminating achievements of all these ages of effort, we shall attempt to discover what was the actual status of Mesopotamian science at its climax. In so far as we succeed, we shall be able to judge what scientific heritage Europe received from the Orient; for in the records of Babylonian science we have to do with the Eastern mind at its best. Let us turn to the specific inquiry as to the achievements of the Chaldean scientist whose fame so dazzled the eyes of his contemporaries of the classic world.

BABYLONIAN ASTRONOMY

Our first concern naturally is astronomy, this being here, as in Egypt, the first-born and the most important of the sciences. The fame of the Chaldean astronomer was indeed what chiefly commanded the admiration of the Greeks, and it was through the results of astronomical observations that Babylonia transmitted her most important influences to the Western world. "Our division of time is of Babylonian origin," says Hommel;[7] "to Babylonia we owe the week of seven days, with the names of the planets for the days of the week, and the division into hours and months." Hence the almost personal interest which we of to-day must needs feel in the efforts of the Babylonian star-gazer.

It must not be supposed, however, that the Chaldean astronomer had made any very extraordinary advances upon the knowledge of the Egyptian "watchers of the night." After all, it required patient observation rather than any peculiar genius in the observer to note in the course of time such broad astronomical conditions as the regularity of the moon's phases, and the relation of the lunar periods to the longer periodical oscillations of the sun. Nor could the curious wanderings of the planets escape the attention of even a moderately keen observer. The chief distinction between the Chaldean and Egyptian astronomers appears to have consisted in the relative importance they attached to various of the phenomena which they both observed. The Egyptian, as we have seen, centred his attention upon the sun. That luminary was the abode of one of his most important gods. His worship was essentially solar. The Babylonian, on the other hand, appears to have been peculiarly impressed with the importance of the moon. He could not, of course, overlook the attention-compelling fact of the solar year; but his unit of time was the lunar period of thirty days, and his year consisted of twelve lunar periods, or 360 days. He was perfectly aware, however, that this period did not coincide with the



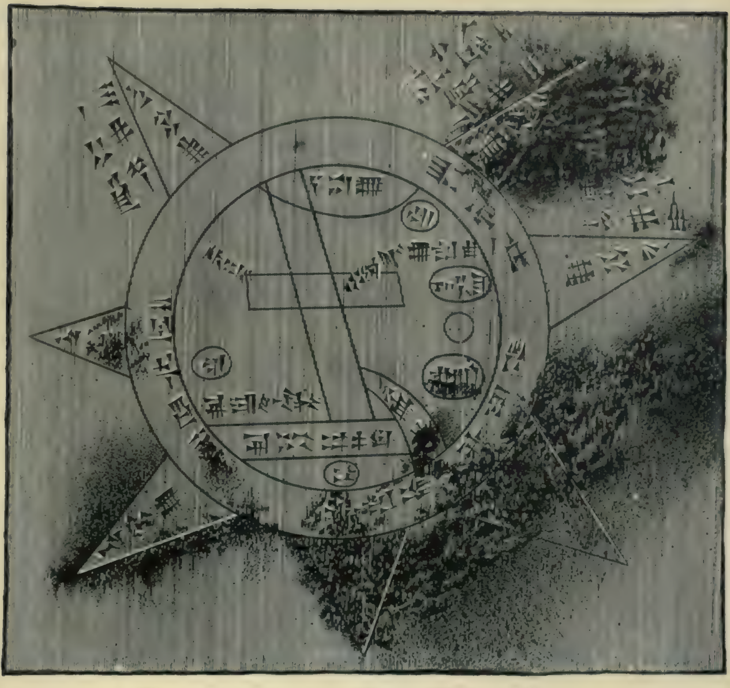
THE WORLD AS CONCEIVED BY THE CHALDEANS

(From a drawing by Faucher-Gudin in Maspero's *Dawn of Civilization.*)

actual year; but the relative unimportance which he ascribed to the solar year is evidenced by the fact that he interpolated an added month to adjust the calendar only once in six years. Indeed, it would appear that the Babylonians and Assyrians did not adopt precisely the same method of adjusting the calendar, since the Babylonians had two intercular months called Elul and Adar, whereas the Assyrians had only a single such month, called the second Adar.[8] (The Ve'Adar of the Hebrews.) This diversity further emphasizes the fact that it was the lunar period which received chief attention, the adjustment of this period with the solar seasons being a necessary expedient of secondary importance. It is held that these lunar periods have often been made to do service for years in the Babylonian computations and in the allied computations of the early Hebrews. The lives of the Hebrew patriarchs, for example, as recorded in the Bible, are perhaps reckoned in lunar "years." Divided by twelve, the "years" of Methuselah accord fairly with the usual experience of mankind.

Yet, on the other hand, the convenience of the solar year in computing long periods of time was not unrecognized, since this period is utilized in reckoning the reigns of the Assyrian kings. It may be added that the reign of a king "was not reckoned from the day of his accession, but from the Assyrian new year's day, either before or after the day of accession. There does not appear to have been any fixed rule as to which new year's day should be chosen; but from the number of known cases, it appears to have been the general practice to count the reigning years from the new year's day nearest the accession, and to call the period between the accession day and the first new year's day 'the beginning of the reign,' when the year from the new year's day was called the first year, and the following ones were brought successively from it. Notwithstanding, in the dates of several Assyrian and Babylonian sovereigns there are cases of the year of accession being considered as the first year, thus giving two reckonings for the reigns of various monarchs, among others, Shalmaneser, Sennacherib, Nebuchadrezzar."[9] This uncertainty as to the years of reckoning again emphasizes the fact that the solar year did not have for the Assyrian chronology quite the same significance that it has for us.

The Assyrian month commenced on the evening when the new moon was first observed, or, in case the moon was not visible, the new month started thirty days after the last month. Since the actual lunar period is about twenty-nine and one-half days, a practical adjustment was required between the months themselves, and this was probably effected by counting alternate months as only 29 days in length. Mr. R. Campbell Thompson[10] is led by his studies of the astrological tablets to emphasize this fact. He believes that "the object of the astrological reports which related to the appearance of the moon and sun was to help determine and foretell the length of the lunar month." Mr. Thompson believes also that there is evidence to show that the interculary month was added at a period less than six years. In point of fact, it does not appear to be quite clearly established as to precisely how the adjustment of days with the lunar months, and



CHALDEAN MAP OF THE WORLD

(From a drawing by Faucher-Gudin in Maspero's *Dawn of Civilization.*)

lunar months with the solar year, was effected. It is clear, however, according to Smith, "that the first 28 days of every month were divided into four weeks of seven days each; the seventh, fourteenth, twenty-first, twenty-eighth days respectively being Sabbaths, and that there was a general prohibition of work on these days." Here, of course, is the foundation of the Hebrew system of Sabbatical days which we have inherited. The sacredness of the number seven itself—the belief in which has not been quite shaken off even to this day—was deduced by the Assyrian astronomer from his observation of the seven planetary bodies—namely, Sin (the moon), Samas (the sun), Umunpawddu (Jupiter), Dilbat (Venus), Kaimanu (Saturn), Gudud (Mercury), Mustabarru-mutanu (Mars).[11] Twelve lunar periods, making up approximately the solar year, gave peculiar importance to the number twelve also. Thus the zodiac was divided into twelve signs which astronomers of all subsequent times have continued to recognize; and the duodecimal system of counting took precedence with the Babylonian mathematicians over the more primitive and, as it seems to us, more satisfactory decimal system.

Another discrepancy between the Babylonian and Egyptian years appears in the fact that the Babylonian new year dates from about the period of the vernal equinox and not from the solstice. Lockyer associates this with the fact that the periodical inundation of the Tigris and Euphrates occurs about the equinoctial period, whereas, as we have seen, the Nile flood comes at the time of the solstice. It is but natural that so important a phenomenon as the Nile flood should make a strong impression upon the minds of a people living in a valley. The fact that occasional excessive inundations have led to most disastrous results is evidenced in the incorporation of stories of the almost total destruction of mankind by such floods among the myth tales of all peoples who reside in valley countries. The flooding of the Tigris and Euphrates had not, it is true, quite the same significance for the Mesopotamians that the Nile flood had for the Egyptians. Nevertheless it was a most important phenomenon, and may very readily be imagined to have been the most tangible index to the seasons. But in recognizing the time of the inundations and the vernal equinox, the Assyrians did not dethrone the moon from its accustomed precedence, for the year was reckoned as commencing not precisely at the vernal equinox, but at the new moon next before the equinox.

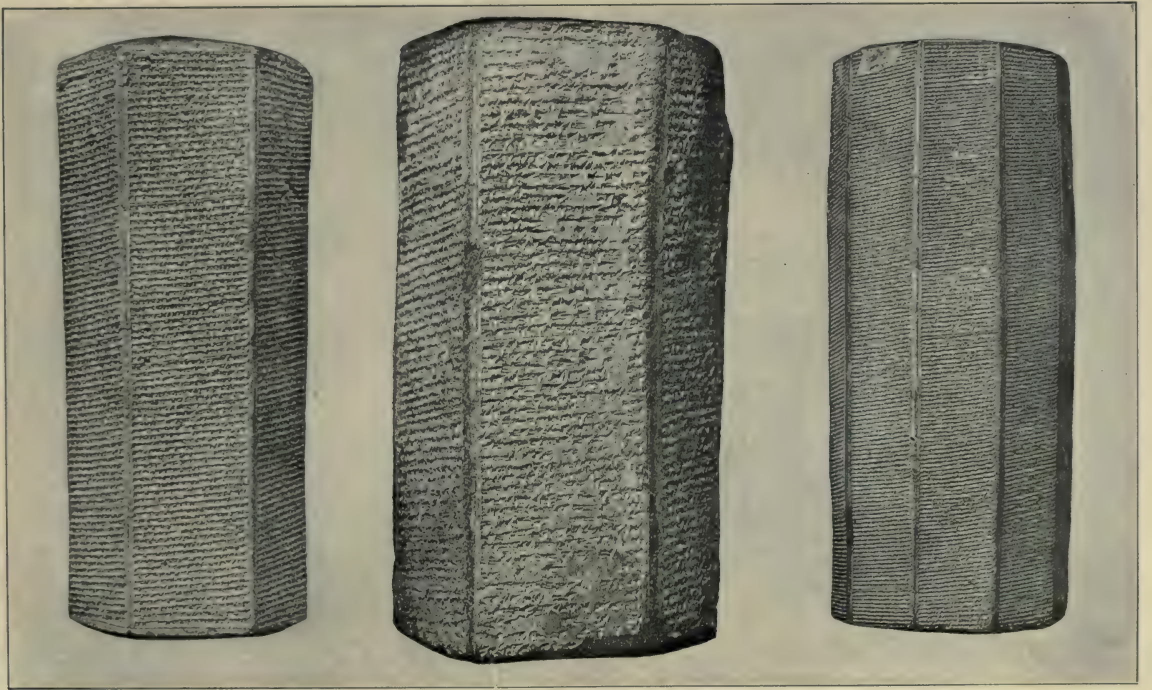
ASTROLOGY

Beyond marking the seasons, the chief interests that actuated the Babylonian astronomer in his observations were astrological. After quoting Diodorus to the effect that the Babylonian priests observed the position of certain stars in order to cast horoscopes, Thompson tells us that from a very early day the very name Chaldean became synonymous with magician. He adds that "from Mesopotamia, by way of Greece and Rome, a certain amount of Babylonian astrology made its way among the nations of the west, and it is quite probable that many superstitions which we commonly record as the peculiar product of western civilization took their origin from those of the early dwellers on the alluvial lands of Mesopotamia. One Assurbanipal, king of Assyria B.C. 668–626, added to the royal library at Nineveh his contribution of tablets, which included many series of documents which related exclusively to the astrology of the ancient Babylonians, who in turn had borrowed it with modifications from the Sumerian invaders of the country. Among these must be mentioned the series which was commonly called 'the Day of Bel,' and which was decreed by the learned to have been written in the time of the great Sargon I., king of Agade, 3800 B.C. With such ancient works as these to guide them, the profession of deducing omens from daily events reached such a pitch of importance in the last Assyrian Empire that a system of making periodical reports came into being. By these the king was informed of all the occurrences in the heavens and on earth, and the results of astrological studies in respect to after events. The heads of the astrological profession were men of high rank and position, and their office was hereditary. The variety of information contained in these reports is best gathered from the fact that they were sent from cities as far removed from each other as Assur in the north and Erech in the south, and it can only be assumed that they were despatched by runners, or men mounted on swift horses. As reports also came from Dilbat, Kutha, Nippur, and Bursippa, all cities of ancient foundation, the king was probably well acquainted with the general course of events in his empire." [12]

From certain passages in the astrological tablets, Thompson draws the interesting conclusion that the Chaldean astronomers were acquainted with some kind of a machine for reckoning time. He finds in one of the tablets a phrase which he interprets to mean measure-governor, and he infers from this the existence of a kind of a calculator. He calls attention also to the fact that Sextus Empiricus[13] states that the clepsydra was known to the Chaldeans, and that Herodotus asserts that the Greeks borrowed certain measures of time from the Babylonians. He finds further corroboration in the fact that the Babylonians had a time-measure by which they divided the day and the night; a measure called kasbu, which contained two hours. In a report relating to the day of the vernal equinox, it is stated that there are six kasbu of the day and six kasbu of the night.

While the astrologers deduced their omens from all the celestial bodies known to them, they chiefly gave attention to the moon, noting with great care the shape of its horns, and deducing such a conclusion as that "if the horns are pointed the king will overcome whatever he goreth," and that "when the moon is low at its appearance, the submission (of the people) of a far country will come."[14] The relations of the moon and sun were a source of constant observation, it being noted whether the sun and moon were seen together above the horizon; whether one set as the other rose, and the like. And whatever the phenomena, there was always, of course, a direct association between such phenomena and the well-being of human kind—in particular the king, at whose instance, and doubtless at whose expense, the observations were carried out.

From omens associated with the heavenly bodies it is but a step to omens based upon other phenomena of nature, and we shall see in a moment that the Babylo-



ASSYRIAN BAKED CLAY PRISMS, WITH INSCRIPTIONS OF KINGS SENNACHERIB (705–681, B.C.), ESARHADDON (681–668, B.C.), AND ASHUR-BANI-PAL (668–626, B.C.)

(Now in the British Museum.)

nian prophets made free use of their opportunities in this direction also. But before we turn from the field of astronomy, it will be well to inform ourselves as to what system the Chaldean astronomer had invented in explanation of the mechanics of the universe. Our answer to this inquiry is not quite as definite as could be desired, the vagueness of the records, no doubt, coinciding with the like vagueness in the minds of the Chaldeans themselves. So far as we can interpret the somewhat mystical references that have come down to us, however, the Babylonian cosmology would seem to have represented the earth as a circular plane surrounded by a great circular river, beyond which rose an impregnable barrier of mountains, and resting upon an infinite sea of waters. The material vault of the heavens was supposed to find support upon the outlying circle of mountains, But the precise mechanism through which the observed revolution of the heavenly bodies was effected remains here, as with the Egyptian cosmology, somewhat conjectural. The simple fact would appear to be that, for the Chaldeans as for the Egyptians, despite their most careful observations of the tangible phenomena of the heavens, no really satisfactory mechanical conception of the cosmos was attainable. We shall see in due course by what faltering steps the European imagination advanced from the crude ideas of Egypt and Babylonia to the relatively clear vision of Newton and Laplace.

CHALDEAN MAGIC

We turn now from the field of the astrologer to the closely allied province of Chaldean magic—a province which includes the other; which, indeed, is so all-encompassing as scarcely to leave any phase of Babylonian thought outside its bounds.

The tablets having to do with omens, exorcisms, and the like magic practices make up an astonishingly large proportion of the Babylonian records. In viewing them it is hard to avoid the conclusion that the superstitions which they evidenced absolutely dominated the life of the Babylonians of every degree. Yet it must not be forgotten that the greatest inconsistencies everywhere exist between the superstitious beliefs of a people and the practical observances of that people. No other problem is so difficult for the historian as that which confronts him when he endeavors to penetrate the mysteries of an alien religion; and when, as in the present case, the superstitions involved have been transmitted from generation to generation, their exact practical phases as interpreted by any particular generation must be somewhat problematical. The tablets upon which our knowledge of these omens is based are many of them from the libraries of the later kings of Nineveh; but the omens themselves are, in such cases, inscribed in the original Accadian form in which they have come down from remote ages, accompanied by an Assyrian translation. Thus the superstitions involved had back of them hundreds of years, even thousands of years, of precedent; and we need not doubt that the ideas with which they are associated were interwoven with almost every thought and deed of the life of the people. Professor Sayce assures us that the Assyrians and Babylonians counted no fewer than three hundred spirits of heaven, and six hundred spirits of earth. "Like the Jews of the Talmud," he says, "they believed that the world was swarming with noxious spirits, who produced the various diseases to which man is liable, and might be swallowed with the food and drink which support life." Fox Talbot was inclined to believe that exorcisms were the exclusive means used to drive away the tormenting spirits. This seems unlikely, considering the uniform association of drugs with the magical practices among their people. Yet there is certainly a strange silence of the tablets in regard to medicine. Talbot tells us that sometimes divine images were brought into the sick-chamber, and written texts taken from holy books were placed on the walls and bound around the sick man's members. If these failed, recourse was had to the influence of the mamit, which the evil powers were unable to resist. On a tablet, written in the Accadian language only, the Assyrian version being taken, however, was found the following:

1. Take a white cloth. In it place the mamit,
2. in the sick man's right hand.
3. Take a black cloth,
4. wrap it around his left hand.
5. Then all the evil spirits (a long list of them is given)
6. and the sins which he has committed
7. shall quit their hold of him
8. and shall never return.

The symbolism of the black cloth in the left hand seems evident. The dying man repents of his former evil deeds, and he puts his trust in holiness, symbolized by the white cloth in his right hand. Then follow some obscure lines about the spirits:

1. Their heads shall remove from his head.
2. Their heads shall let go his hands.
3. Their feet shall depart from his feet.

Which perhaps may be explained thus: we learn from another tablet that the various classes of evil spirits troubled different parts of the body; some injured the head, some the hands and the feet, etc., therefore the passage before may mean "the spirits whose power is over the hand shall loose their hands from his," etc. "But," concludes Talbot, "I can offer no decided opinion upon such obscure points of their superstition."[15]

In regard to evil spirits, as elsewhere, the number seven had a peculiar significance, it being held that that number of spirits might enter into a man together. Talbot has translated[16] a "wild chant" which he names "The Song of the Seven Spirits."

1. There are seven! There are seven!
2. In the depths of the ocean there are seven!
3. In the heights of the heaven there are seven!
4. In the ocean stream in a palace they were born.
5. Male they are not: female they are not!
6. Wives they have not! Children are not born to them!
7. Rules they have not! Government they know not!
8. Prayers they hear not!
9. There are seven! There are seven! Twice over there are seven!

The tablets make frequent allusion to these seven spirits. One starts thus:

1. The god (——) shall stand by his bedside;
2. These seven evil spirits he shall root out and shall expel them from his body,
3. and these seven shall never return to the sick man again.[17]

Altogether similar are the exorcisms intended to ward off disease. Professor Sayce has published translations of some of these.[18] Each of these ends with the same phrase, and they differ only in regard to the particular maladies from which freedom is desired. One reads:

> "From wasting, from want of health, from the evil spirit of the ulcer, from the spreading quinsy of the gullet, from the violent ulcer, from the noxious ulcer, may the king of heaven preserve, may the king of earth preserve."

Another is phrased thus:

> "From the cruel spirit of the head, from the strong spirit of the head, from the head spirit that departs not, from the head spirit that comes not forth, from the head spirit that will not go, from the noxious head spirit, may the king of heaven preserve, may the king of earth preserve."

As to omens having to do with the affairs of everyday life the number is legion. For example, Moppert has published, in the *Journal Asiatique*,[19] the translation of a tablet which contains on its two sides several scores of birth-portents, a few of which may be quoted at random:

> "When a woman bears a child and it has the ears of a lion, a strong king is in the country." "When a woman bears a child and it has a bird's beak, that country is oppressed." "When a woman bears a child and its right hand is wanting, that country goes to destruction." "When a woman bears a child and its feet are wanting, the roads of the country are cut; that house is destroyed." "When a woman bears a child and at the time of its birth its beard is grown, floods are in the country." "When a woman bears a child and at the time of its birth its mouth is open and speaks, there is

pestilence in the country, the Air-god inundates the crops of the country, injury in the country is caused."

Some of these portents, it will be observed, are not in much danger of realization, and it is curious to surmise by what stretch of the imagination they can have been invented. There is, for example, on the same tablet just quoted, one reference which assures us that "when a sheep bears a lion the forces march multitudinously; the king has not a rival." There are other omens, however, that are so easy of realization as to lead one to suppose that any Babylonian who regarded all the superstitious signs must have been in constant terror. Thus a tablet translated by Professor Sayce[20] gives a long list of omens furnished by dogs, in which we are assured that:

1. If a yellow dog enters into the palace, exit from that palace will be baleful.
2. If a dog to the palace goes, and on a throne lies down, that palace is burned.
3. If a black dog into a temple enters, the foundation of that temple is not stable.
4. If female dogs one litter bear, destruction to the city.

It is needless to continue these citations, since they but reiterate endlessly the same story. It is interesting to recall, however, that the observations of animate nature, which were doubtless superstitious in their motive, had given the Babylonians some inklings of a knowledge of classification. Thus, according to Menant,[21] some of the tablets from Nineveh, which are written, as usual, in both the Sumerian and Assyrian languages, and which, therefore, like practically all Assyrian books, draw upon the knowledge of old Babylonia, give lists of animals, making an attempt at classification. The dog, lion, and wolf are placed in one category; the ox, sheep, and goat in another; the dog family itself is divided into various races, as the domestic dog, the coursing dog, the small dog, the dog of Elan, etc. Similar attempts at classification of birds are found. Thus, birds of rapid flight, sea-birds, and marsh-birds are differentiated. Insects are classified according to habit; those that attack plants, animals, clothing, or wood. Vegetables seem to be classified according to their usefulness. One tablet enumerates the uses of wood according to its adaptability for timber-work of palaces, or construction of vessels, the making of implements of husbandry, or even furniture. Minerals occupy a long series in these tablets. They are classed according to their qualities, gold and silver occupying a division apart; precious stones forming another series. Our Babylonians, then, must be credited with the development of a rudimentary science of natural history.

BABYLONIAN MEDICINE

We have just seen that medical practice in the Babylonian world was strangely under the cloud of superstition. But it should be understood that our estimate, through lack of correct data, probably does much less than justice to the attainments of the physician of the time. As already noted, the existing tablets chance not to throw much light on the subject. It is known, however, that the practitioner of medicine occupied a position of some authority and responsibility.

The proof of this is found in the clauses relating to the legal status of the physician which are contained in the now famous code[22] of the Babylonian King Khamurabi, who reigned about 2300 years before our era. These clauses, though throwing no light on the scientific attainments of the physician of the period, are too curious to be omitted. They are clauses 215 to 227 of the celebrated code, and are as follows:

215. If a doctor has treated a man for a severe wound with a lancet of bronze and has cured the man, or has opened a tumor with a bronze lancet and has cured the man's eye, he shall receive ten shekels of silver.

216. If it was a freedman, he shall receive five shekels of silver.

217. If it was a man's slave, the owner of the slave shall give the doctor two shekels of silver.

218. If a physician has treated a free-born man for a severe wound with a lancet of bronze and has caused the man to die, or has opened a tumor of the man with a lancet of bronze and has destroyed his eye, his hands one shall cut off.

219. If the doctor has treated the slave of a freedman for a severe wound with a bronze lancet and has caused him to die, he shall give back slave for slave.

220. If he has opened his tumor with a bronze lancet and has ruined his eye, he shall pay the half of his price in money.

221. If a doctor has cured the broken limb of a man, or has healed his sick body, the patient shall pay the doctor five shekels of silver.

222. If it was a freedman, he shall give three shekels of silver.

223. If it was a man's slave, the owner of the slave shall give two shekels of silver to the doctor.

224. If the doctor of oxen and asses has treated an ox or an ass for a grave wound and has cured it, the owner of the ox or the ass shall give to the doctor as his pay one-sixth of a shekel of silver.

225. If he has treated an ox or an ass for a severe wound

and has caused its death, he shall pay one-fourth of its price to the owner of the ox or the ass.

226. If a barber-surgeon, without consent of the owner of a slave, has branded the slave with an indelible mark, one shall cut off the hands of that barber.

227. If any one deceive the surgeon-barber and make him brand a slave with an indelible mark, one shall kill that man and bury him in his house. The barber shall swear, "I did not mark him wittingly," and he shall be guiltless.

ESTIMATES OF BABYLONIAN SCIENCE

Before turning from the Oriental world it is perhaps worth while to attempt to estimate somewhat specifically the world-influence of the name, Babylonian science. Perhaps we cannot better gain an idea as to the estimate put upon that science by the classical world than through a somewhat extended quotation from a classical author. Diodorus Siculus, who, as already noted, lived at about the time of Augustus, and who, therefore, scanned in perspective the entire sweep of classical Greek history, has left us a striking summary which is doubly valuable because of its comparisons of Babylonian with Greek influence. Having viewed the science of Babylonia in the light of the interpretations made possible by the recent study of original documents, we are prepared to draw our own conclusions from the statements of the Greek historian. Here is his estimate in the words of the quaint translation made by Philemon Holland in the year 1700:[23]

"They being the most ancient Babylonians, hold the same station and dignity in the Common-wealth as the Egyptian Priests do in Egypt: For being deputed to Divine Offices, they spend all their Time in the study of Philosophy, and are especially famous for the Art of Astrology. They are mightily given to Divination, and foretel future Events, and imploy themselves either by Purifications, Sacrifices, or other Inchantments to avert Evils, or procure good Fortune and Success. They are skilful likewise in the Art of Divination, by the flying of Birds, and interpreting of Dreams and Prodigies: And are reputed as true Oracles (in declaring what will come to pass) by their exact and diligent viewing the Intrals of the Sacrifices. But they attain not to this Knowledge in the same manner as the Grecians do; for the Chaldeans learn it by Tradition from their Ancestors, the Son from the Father, who are all in the mean time free from all other publick Offices and Attendances; and because their Parents are their Tutors, they both learn every thing without Envy, and rely with more confidence upon the truth of what is taught them; and being train'd up in this Learning from their very Childhood, they become most famous Philosophers, (that Age being most capable of Learning, wherein they spend much of their time). But the Grecians for the most part come raw to this study, unfitted and unprepar'd, and are long before they attain to the Knowledge of this Philosophy: And after they have spent some small time in this Study, they are many times call'd off and forc'd to leave it, in order to get a Livelihood and Subsistence. And although some few do industriously apply themselves to Philosophy, yet for the sake of Gain, these very Men are opinionative, and ever and anon starting new and high Points, and never fix in the steps of their Ancestors. But the Barbarians keeping constantly close to the same thing, attain to a perfect and distinct Knowledge in every particular.

"But the Grecians, cunningly catching at all Opportunities of Gain, make new Sects and Parties, and by their contrary Opinions wrangling and quarelling concerning the chiefest Points, lead their Scholars into a Maze; and being uncertain and doubtful what to pitch upon for certain truth, their Minds are fluctuating and in suspence all the days of their Lives, and unable to give a certain assent unto any thing. For if any Man will but examine the most eminent Sects of the Philosophers, he shall find them much differing among themselves, and even opposing one another in the most weighty parts of their Philosophy. But to return to the Chaldeans, they hold that the World is eternal, which had neither any certain Beginning, nor shall have any End; but all agree, that all things are order'd, and this beautiful Fabrick is supported by a Divine Providence, and that the Motions of the Heavens are not perform'd by chance and of their own accord, but by a certain and determinate Will and Appointment of the Gods.

"Therefore from a long observation of the Stars, and an exact Knowledge of the motions and influences of every one of them, wherein they excel all others, they fortel many things that are to come to pass.

"They say that the Five Stars which some call Planets, but they Interpreters, are most worthy of Consideration, both for their motions and their remarkable influences, especially that which the Grecians call Saturn. The brightest of them all, and which often portends many and great Events, they call Sol, the other Four they name Mars, Venus, Mercury, and Jupiter, with our own Country Astrologers. They give the Name of Interpreters to these Stars, because these only by a peculiar Motion do portend things to come, and instead of Jupiters, do declare to Men before-hand the good-will of the Gods; whereas the other Stars (not being of the number of the Planets) have a constant ordinary motion. Future Events (they say) are pointed at sometimes by their Rising, and sometimes by their Setting, and at other times by their Colour, as may be experienc'd by those that will diligently observe it; sometimes foreshewing Hurricanes, at other times Tempestuous Rains, and then again exceeding Droughts. By these, they say, are often portended the appearance of Comets, Eclipses of the Sun and Moon, Earthquakes and all other the various Changes and remarkable effects in the Air, boding good and bad, not only to Nations in general, but to Kings and Private Persons in particular. Under the course of these Planets, they say are Thirty Stars, which they call Counselling Gods, half of whom observe what is done under the Earth, and the other half take notice of the actions of Men upon the Earth, and what is transacted in the Heavens. Once every Ten Days space (they say) one of the highest Order of these Stars descends to them that are of the lowest, like a Messenger sent from them above; and then again another ascends from those below to them above, and that this is their constant natural motion to continue for ever. The chief of these Gods, they say, are Twelve in number, to each of which they attribute a Month, and one Sign of the Twelve in the Zodiack.

"Through these Twelve Signs the Sun, Moon, and the other Five Planets run their Course. The Sun in a Years time, and the Moon in the space of a Month. To every one of the Planets they assign their own proper Courses, which are perform'd variously in lesser or shorter time according as their several motions are quicker or slower. These Stars, they say, have a great influence both as to good and bad in Mens Nativities; and from the consideration of their several Natures, may be foreknown what will befal Men afterwards. As they foretold things to come to other Kings formerly, so they did to Alexander who conquer'd Darius, and to his Successors Antigonus and Seleucus Nicator; and accordingly things fell out as they declar'd; which we shall relate particularly hereafter in a more convenient time. They tell likewise private Men their Fortunes so certainly, that those who have found the thing true by Experience, have esteem'd it a Miracle, and above the reach of man to perform. Out of the Circle of the Zodiack they describe Four and Twenty Stars, Twelve towards the North Pole, and as many to the South.

"Those which we see, they assign to the living; and the other that do not appear, they conceive are Constellations for the Dead; and they term them Judges of all things. The Moon, they say, is in the lowest Orb; and being therefore next to the Earth (because she is so small), she finishes her Course in a little time, not through the swiftness of her Motion, but the shortness of her Sphear. In that which they affirm (that she has but a borrow'd light, and that when she is eclips'd, it's caus'd by the interposition of the shadow of the Earth) they agree with the Grecians.

"Their Rules and Notions concerning the Eclipses of the Sun are but weak and mean, which they dare not positively foretel, nor fix a certain time for them. They have likewise Opinions concerning the Earth peculiar to themselves, affirming it to resemble a Boat, and to be hollow, to prove which, and other things relating to the frame of the World, they abound in Arguments; but to give a particular Account of 'em, we conceive would be a thing foreign to our History. But this any Man may justly and truly say, That the Chaldeans far exceed all other Men in the Knowledge of Astrology, and have study'd it most of any other Art or Science: But the number of years during which the Chaldeans say, those of their Profession have given themselves to the study of this natural Philosophy, is incredible; for when Alexander was in Asia, they reckon'd up Four Hundred and Seventy Thousand Years since they first began to observe the Motions of the Stars."

Let us now supplement this estimate of Babylonian influence with another estimate written in our own day, and quoted by one of the most recent historians of Babylonia and Assyria.[24] The estimate in question is that of Canon Rawlinson in his *Great Oriental Monarchies*.[25] Of Babylonia he says:

"Hers was apparently the genius which excogitated an alphabet; worked out the simpler problems of arithmetic; invented implements for measuring the lapse of time; conceived the idea of raising enormous structures with the poorest of all materials, clay; discovered the art of polishing, boring, and engraving gems; reproduced with truthfulness the outlines of human and animal forms; attained to high perfection in textile fabrics; studied with success the motions of the heavenly bodies; conceived of grammar as a science; elaborated a system of law; saw the value of an exact chronology—in almost every branch of science made a beginning, thus rendering it comparatively easy for other nations to proceed with the superstructure. . . . It was from the East, not from Egypt, that Greece derived her architecture, her sculpture, her science, her philosophy, her mathematical knowledge—in a word, her intellectual life. And Babylon was the source to which the entire stream of Eastern civilization may be traced. It is scarcely too much to say that, but for Babylon, real civilization might not yet have dawned upon the earth."

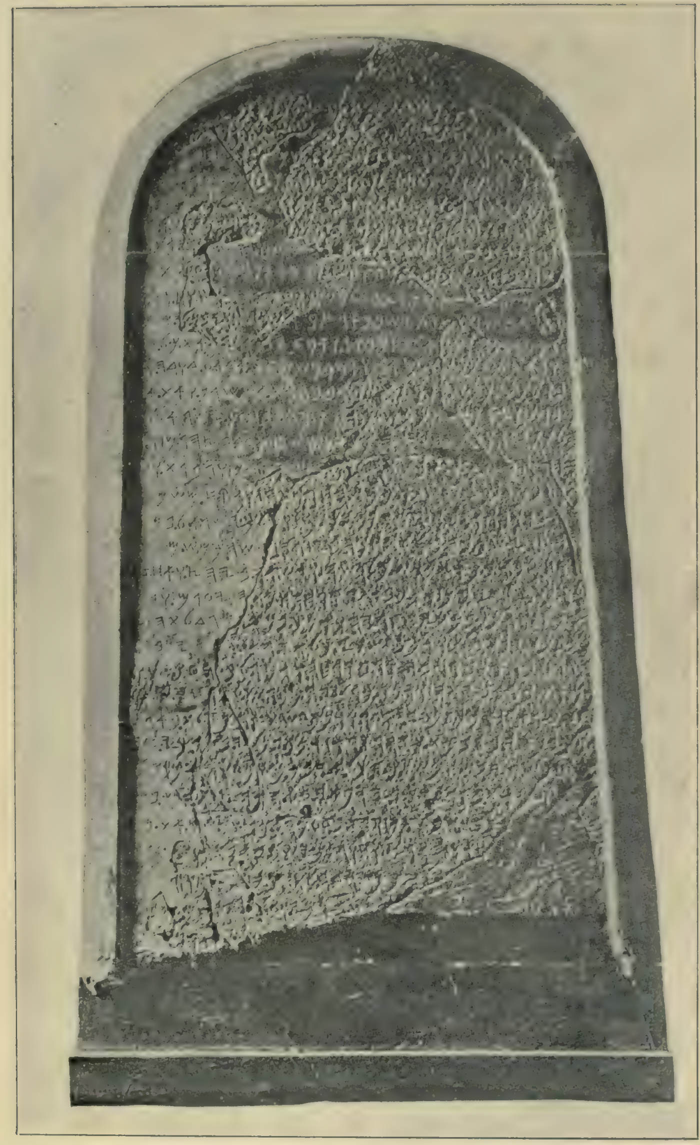
Considering that a period of almost two thousand years separates the times of writing of these two estimates, the estimates themselves are singularly in unison. They show that the greatest of Oriental nations has not suffered in reputation at the hands of posterity. It is indeed almost impossible to contemplate the monuments of Babylonian and Assyrian civilization that are now preserved in the European and American museums without becoming enthusiastic. That certainly was a wonderful civilization which has left us the tablets on which are inscribed the laws of a Khamurabi on the one hand, and the art treasures of the palace of an Asshurbanipal on the other. Yet a candid consideration of the scientific attainments of the Babylonians and Assyrians can scarcely arouse us to a like enthusiasm. In considering the subject we have seen that, so far as pure science is concerned, the efforts of the Babylonians and Assyrians chiefly centred about the subjects of astrology and magic. With the records of their ghost-haunted science fresh in mind, one might be forgiven for a momentary desire to take issue with Canon Rawlinson's words. We are assured that the scientific attainments of Europe are almost solely to be credited to Babylonia and not to Egypt, but we should not forget that Plato, the greatest of the Greek thinkers, went to Egypt and not to Babylonia to pursue his studies when he wished to penetrate the secrets of Oriental science and philosophy. Clearly, then, classical Greece did not consider Babylonia as having a monopoly of scientific knowledge, and we of to-day, when we attempt to weigh the new evidence that has come to us in recent generations with the Babylonian records themselves, find that some, at least, of the heritages for which Babylonia has been praised are of more than doubtful value. Babylonia, for example, gave us our seven-day week and our system of computing by twelves. But surely the world could have got on as well without that magic number seven; and after some hundreds of generations we are coming to feel that the decimal system of the Egyptians has advantages over the duodecimal system of the Babylonians. Again, the Babylonians did not invent the alphabet; they did not even accept it when all the rest of the world had recognized its value. In grammar and arithmetic, as with astronomy, they seemed not to have advanced greatly, if at all, upon the Egyptians. One field in which they stand out in startling pre-eminence is the field of astrology; but this, in the estimate of modern thought, is the very negation of science. Babylonia impressed her superstitions on the Western world, and when we consider the baleful influence of these superstitions, we may almost question whether we might not reverse Canon Rawlinson's estimate and say that perhaps but for Babylonia real civilization, based on the application of true science, might have dawned upon the earth a score of centuries before it did. Yet, after all, perhaps this estimate is unjust. Society, like an individual organism, must creep before it can walk, and perhaps the Babylonian experiments in astrology and magic, which European civilization was destined to copy for some three or four thousand years, must have been made a part of the necessary evolution of our race in one place or in another. That thought, however, need not blind us to the essential fact, which the historian of science must needs admit, that for the Babylonian, despite his boasted culture, science spelled superstition.

IV

THE DEVELOPMENT OF THE ALPHABET

BEFORE we turn specifically to the new world of the west, it remains to take note of what may perhaps be regarded as the very greatest achievement of ancient science. This was the analysis of speech sounds, and the resulting development of a system of alphabetical writing. To comprehend the series of scientific inductions which led to this result, we must go back in imagination and trace briefly the development of the methods of recording thought by means of graphic symbols. In other words, we must trace the evolution of the art of writing. In doing so we cannot hold to national lines as we have done in the preceding two chapters, though the efforts of the two great scientific nations just considered will enter prominently into the story.

The familiar Greek legend assures us that a Phœnician named Kadmus was the first to bring a knowledge of letters into Europe. An elaboration of the story, current throughout classical times, offered the further explanation that the Phœnicians had in turn acquired the art of writing from the Egyptians or Babylonians. Knowledge as to the true origin and development of the art of writing did not extend in antiquity beyond such vagaries as these. Nineteenth-century studies gave the first real clews to an



THE MOABITE STONE

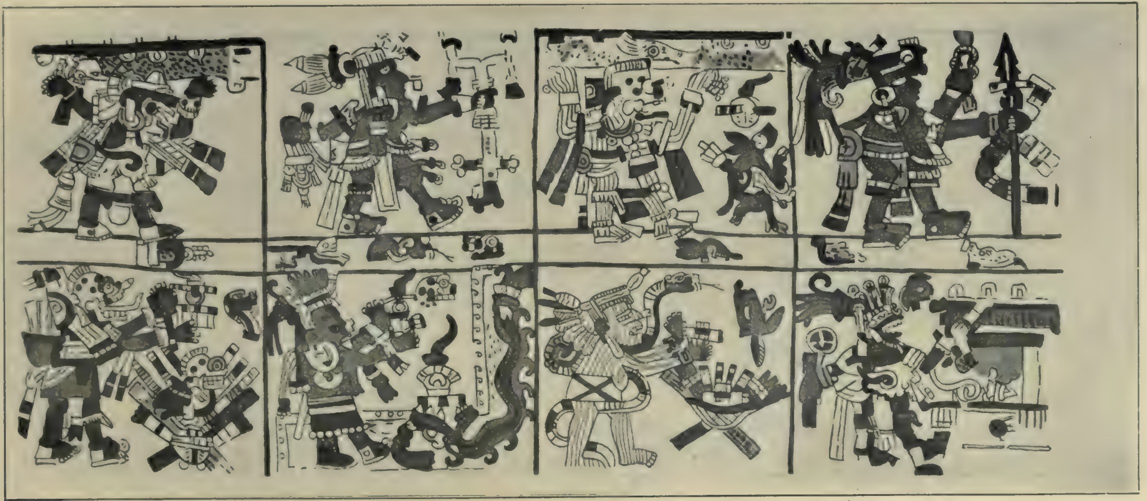
(With one possible exception the oldest known example of the Phœnician writing. It shows an inscription of Mesha, king of Moab, and dates from early in the ninth century, B.C.)

understanding of the subject. These studies tended to authenticate the essential fact on which the legend of Kadmus was founded; to the extent, at least, of making it probable that the later Grecian alphabet was introduced from Phœnicia—though not, of course, by any individual named Kadmus, the latter being, indeed, a name of purely Greek origin. Further studies of the past generation tended to corroborate the ancient belief as to the original source of the Phœnician alphabet, but divided scholars between two opinions: the one contending that the Egyptian hieroglyphics were the source upon which the Phœnicians drew; and the other contending with equal fervor that the Babylonian wedge character must be conceded that honor.

But, as has often happened in other fields after years of acrimonious controversy, a new discovery or two may suffice to show that neither contestant was right. After the Egyptologists of the school of De Rouge[1] thought they had demonstrated that the familiar symbols of the Phœnician alphabet had been copied from that modified form of Egyptian hieroglyphics known as the hieratic writing, the Assyriologists came forward to prove that certain characters of the Babylonian syllabary also show a likeness to the alphabetical characters that seemingly could not be due to chance. And then, when a settlement of the dispute seemed almost hopeless, it was shown through the Egyptian excavations that characters even more closely resembling those in dispute had been in use all about the shores of the Mediterranean, quite independently of either Egyptian or Assyrian writings, from periods so ancient as to be virtually prehistoric.

Coupled with this disconcerting discovery are the revelations brought to light by the excavations at the sites of Knossos and other long-buried cities of the island of Crete.[2] These excavations, which are still in progress, show that the art of writing was known and practised independently in Crete before that cataclysmic overthrow of the early Greek civilization which archæologists are accustomed to ascribe to the hypothetical invasion of the Dorians. The significance of this is that the art of writing was known in Europe long before the advent of the mythical Kadmus. But since the early Cretan scripts are not to be identified with the scripts used in Greece in historical times, whereas the latter are undoubtedly of lineal descent from the Phœnician alphabet, the validity of the Kadmus legend, in a modified form, must still be admitted.

As has just been suggested, the new knowledge, particularly that which related to the great antiquity of characters similar to the Phœnician alphabetical signs, is somewhat disconcerting. Its general trend, however, is quite in the same direction with most of the new archæological knowledge of recent decades—that is to say, it tends to emphasize the idea that human civilization in most of its important elaborations is vastly older than has hitherto been supposed. It may be added, however, that no definite clews are as yet available that enable us to fix even an approximate date for the origin of the Phœnician alphabet. The signs, to which reference has been made, may well have been in existence for thousands of years, utilized merely as property marks, symbols for count-



MEXICAN PICTURE-WRITING

(Probably of the fourteenth or fifteenth century, A.D. The original is now MS. 3773 of the Vatican Library, Rome. Reproduced from Williams' *History of the Art of Writing*.)

ing and the like, before the idea of setting them aside as phonetic symbols was ever conceived. Nothing is more certain, in the judgment of the present-day investigator, than that man learned to write by slow and painful stages. It is probable that the conception of such an analysis of speech sounds as would make the idea of an alphabet possible came at a very late stage of social evolution, and as the culminating achievement of a long series of improvements in the art of writing. The precise steps that marked this path of intellectual development can for the most part be known only by inference; yet it is probable that the main chapters of the story may be reproduced with essential accuracy.

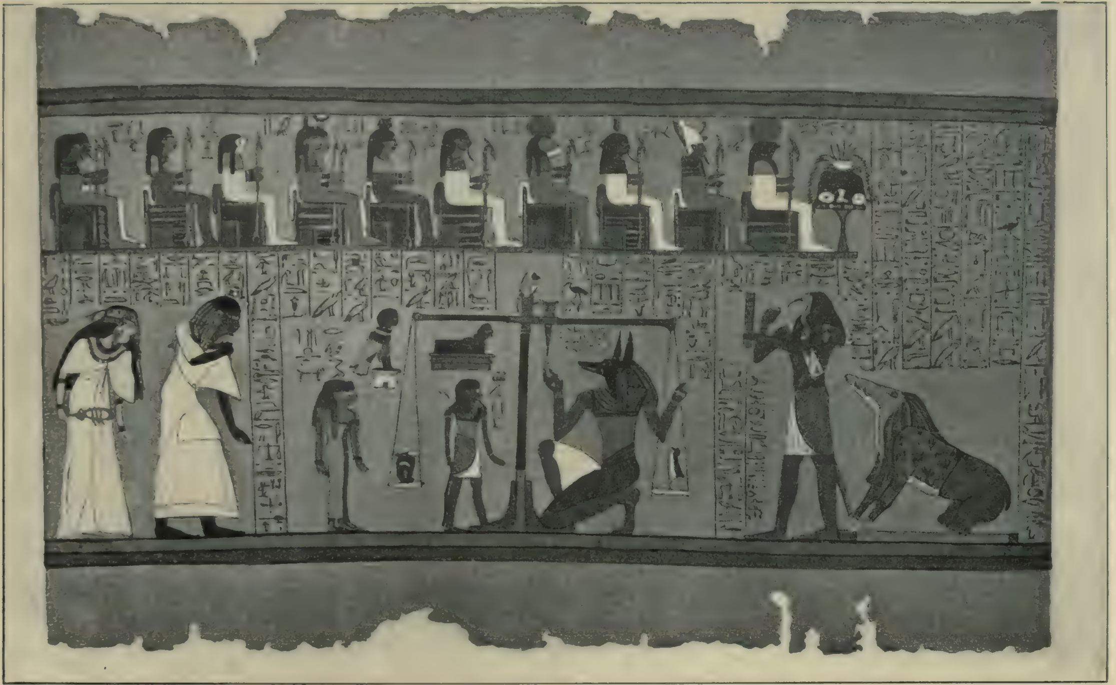
FIRST STEPS

For the very first chapters of the story we must go back in imagination to the prehistoric period. Even barbaric man feels the need of self-expression, and strives to make his ideas manifest to other men by pictorial signs. The cave-dwellers scratched pictures of men and animals on the surface of a reindeer horn or mammoth tusk as mementos of his prowess. The American Indian does essentially the same thing to-day, making pictures that crudely record his successes in war and the chase. The Northern Indian had got no farther than this when the white man discovered America; but the Aztecs of the Southwest and the Maya people of Yucatan had carried their picture-making to a much higher state of elaboration.[3] They had developed systems of pictographs or hieroglyphics that would doubtless in the course of generations have been elaborated into alphabetical systems, had not the Europeans cut off the civilization of which they were the highest exponents.

What the Aztec and Maya were striving towards in the sixteenth century A.D., various Oriental nations had attained at least five or six thousand years earlier. In Egypt at the time of the pyramid-builders, and in Babylonia at the same epoch, the people had developed systems of writing that enabled them not merely to present a limited range of ideas pictorially, but to express in full elaboration and with finer shades of meaning all the ideas that pertain to highly cultured existence. The man of that time made records of military achievements, recorded the transactions of every-day business life, and gave expression to his moral and spiritual aspirations in a way strangely comparable to the manner of our own time. He had perfected highly elaborate systems of writing.

EGYPTIAN WRITING

Of the two ancient systems of writing just referred to as being in vogue at the so-called dawnings of history, the more picturesque and suggestive was the hieroglyphic system of the Egyptians. This is a curiously conglomerate system of writing, made up in part of symbols reminiscent of the crudest stages of picture-writing, in part of symbols having the phonetic value of syllables, and in part of true alphabetical letters. In a word, the Egyptian writing represents in itself the elements of the various stages through which the art of writing has developed.[4] We must conceive



REPRODUCTION OF A FRAGMENT OF THE EGYPTIAN BOOK OF THE DEAD

(Reproduced from Williams' *History of the Art of Writing.*)

that new features were from time to time added to it, while the old features, curiously enough, were not given up.

Here, for example, in the midst of unintelligible lines and pot-hooks, are various pictures that are instantly recognizable as representations of hawks, lions, ibises, and the like. It can hardly be questioned that when these pictures were first used calligraphically they were meant to represent the idea of a bird or animal. In other words, the first stage of picture-writing did not go beyond the mere representation of an eagle by the picture of an eagle. But this, obviously, would confine the presentation of ideas within very narrow limits. In due course some inventive genius conceived the thought of symbolizing a picture. To him the outline of an eagle might represent not merely an actual bird, but the thought of strength, of courage, or of swift progress. Such a use of symbols obviously extends the range of utility of a nascent art of writing. Then in due course some wonderful psychologist—or perhaps the joint efforts of many generations of psychologists—made the astounding discovery that the human voice, which seems to flow on in an unbroken stream of endlessly varied modulations and intonations, may really be analyzed into a comparatively limited number of component sounds—into a few hundreds of syllables. That wonderful idea conceived, it was only a matter of time until it would occur to some other enterprising genius that by selecting an arbitrary symbol to represent each one of these elementary sounds it would be possible to make a written record of the words of human speech which could be reproduced—rephonated—by some one who had never heard the words and did not know in advance what this written record contained. This, of course, is what every child learns to do now in the primer class, but we may feel assured that such an idea never occurred to any human being until the peculiar forms of pictographic writing just referred to had been practised for many centuries. Yet, as we have said, some genius of prehistoric Egypt conceived the idea and put it into practical execution, and the hieroglyphic writing of which the Egyptians were in full possession at the very beginning of what we term the historical period made use of this phonetic system along with the ideographic system already described.

So fond were the Egyptians of their pictorial symbols used ideographically that they clung to them persistently throughout the entire period of Egyptian history. They used symbols as phonetic equivalents very frequently, but they never learned to depend upon them exclusively. The scribe always interspersed his phonetic signs with some other signs intended as graphic aids. After spelling a word out in full, he added a picture, sometimes even two or three pictures, representative of the individual thing, or at least of the type of thing to which the word belongs. Two or three illustrations will make this clear.

Thus *qeften*, monkey, is spelled out in full, but the picture of a monkey is added as a determinative; second, *qenu*, cavalry, after being spelled, is made unequivocal by the introduction of a picture of a horse; third, *temati*, wings, though spelled elaborately, has pictures of wings added; and fourth, *tatu*, quadrupeds, after being spelled, has a picture of a quadruped, and then the picture of a hide, which is the usual determinative of a quadruped, followed by three dashes to indicate the plural number.

It must not be supposed, however, that it was a mere whim which led the Egyptians to the use of this system of determinatives. There was sound reason back of it. It amounted to no more than the expedient we adopt when we spell "to," "two," or "too," in indication of a single sound with three different meanings. The Egyptian language abounds in words having more than one meaning, and in writing these it is obvious that some means of distinction is desirable. The same thing occurs even more frequently in the Chinese language, which is monosyllabic. The Chinese adopt a more clumsy expedient, supplying a different symbol for each of the meanings of a syllable; so that while the actual word-sounds of their speech are only a few hundreds in number, the characters of their written language mount high into the thousands.

BABYLONIAN WRITING

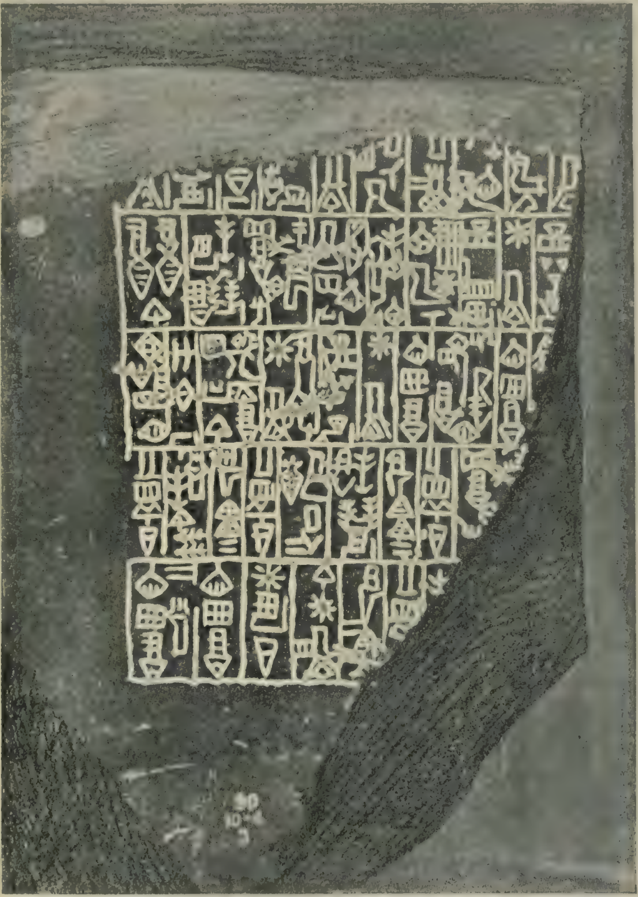
While the civilization of the Nile Valley was developing this extraordinary system of hieroglyphics, the inhabitants of Babylonia were practising the art of writing along somewhat different lines. It is certain that they began with picture-making, and that in due course they advanced to the development of the syllabary; but, unlike their Egyptian cousins, the men of Babylonia saw fit to discard the old system when they had perfected a better one.[5] So at a very early day their writing—as revealed to us now through the recent excavations—had ceased to have that pictorial aspect which distinguishes the Egyptian script. What had originally been pictures of objects—fish, houses, and the like—had come to be represented by mere aggregations of wedge-shaped marks. As the writing of the Babylonians was chiefly inscribed on soft clay, the adaptation of this wedge-shaped mark in lieu of an ordinary line was probably a mere matter of convenience, since the sharp-cornered implement used in making the inscription naturally made a wedge-shaped impression in the clay. That, however, is a detail. The essential thing is that the Babylonian had so fully analyzed the speech-sounds that he felt entire confidence in them, and having selected a sufficient number of conventional characters—each made up of wedge-shaped lines—to represent all the phonetic sounds of his language, spelled the words out in syllables and to some extent dispensed with the determinative signs which, as we have seen, played so prominent a part in the Egyptian writing. His cousins the Assyrians used habitually a system of writing the foundation of which was an elaborate phonetic syllabary; a system, therefore, far removed from the old crude pictograph, and in some respects much more developed than the complicated Egyptian method; yet, after all, a system that stopped short of perfection by the wide gap that separates the syllabary from the true alphabet.

A brief analysis of speech sounds will aid us in understanding the real nature of the syllabary. Let us take for consideration the consonantal sound represented by the letter *b*. A moment's consideration will make it clear that this sound enters into a large number of syllables. There are, for example, at least twenty vowel sounds in the English language, not to speak of certain digraphs; that is to say, each of the important vowels has from two to six sounds. Each of these vowel sounds may enter into combination with the *b* sound alone to form three syllables; as ba, ab, bal, be, eb, bel, etc. Thus there are at least sixty *b*-sound syllables. But this is not the end, for other consonantal sounds may be associated in the syllables in such combinations as bad, bed, bar, bark, cab, etc. As each of the other twenty odd consonantal sounds may enter into similar combinations, it is obvious that there are several hundreds of fundamental syllables to be taken into account in any syllabic system of writing. For each of these syllables a symbol must be set aside and held in reserve as the representative of that particular sound. A perfect syllabary, then, would require some hundred or more of symbols to represent *b* sounds alone; and since the sounds for *c*, *d*, *f*, and the rest are equally varied, the entire syllabary would run into thousands of characters, almost rivalling in complexity the Chinese system. But in practice the most perfect syllabary, such as that of the Babylonians, fell short of this degree of precision through ignoring the minor shades of sound; just as our own alphabet is content to represent some thirty vowel sounds by five letters, ignoring the fact that *a*, for example, has really half a dozen distinct phonetic values. By such slurring of sounds the syllabary is reduced far below its ideal limits; yet even so it retains three or four hundred characters.

In point of fact, such a work as Professor Delitzsch's *Assyrian Grammar*[6] presents signs for three hundred and thirty-four syllables, together with sundry alternative signs and determinatives to tax the memory of the would-be reader of Assyrian. Let us take for example a few of the *b* sounds. It has been explained that the basis of the Assyrian written character is a simple wedge-shaped or arrow-head mark. Variously repeated and grouped, these marks make up the syllabic characters.

To learn some four hundred such signs as these was the task set, as an equivalent of learning the a b c's, to any primer class in old Assyria in the long generations when that land was the culture centre of the world. Nor was the task confined to the natives of Babylonia and Assyria alone. About the fifteenth century B.C., and probably for a long time before and after that period, the exceedingly complex syllabary of the Babylonians was the official means of communication throughout western Asia and between Asia and Egypt, as we know from the chance discovery of a collection of letters belonging to the Egyptian king Khun-aten, preserved at Tel-el-Amarna. In the time of Ramses the Great the Babylonian writing was in all probability considered by a majority of the most highly civilized people in the world to be the most perfect script practicable. Doubtless the average scribe of the time did not in the least realize the waste of energy involved in his labors, or ever suspect that there could be any better way of writing.

Yet the analysis of any one of these hundreds of syllables into its component phonetic elements—had



OLD BABYLONIAN INSCRIPTION.

Date about 4500 B.C.

British Museum, London.

(Reproduced from Williams' *History of the Art of Writing.*)

any one been genius enough to make such analysis—would have given the key to simpler and better things. But such an analysis was very hard to make, as the sequel shows. Nor is the utility of such an analysis self-evident, as the experience of the Egyptians proved. The vowel sound is so intimately linked with the consonant — the *con*-sonant, implying this intimate relation in its very name — that it seemed extremely difficult to give it individual recognition. To set off the mere labial beginning of the sound by itself, and to recognize it as an all-essential element of phonation, was the feat at which human intelligence so long balked. The germ of great things lay in that analysis. It was a process of simplification, and all art development is from the complex to the simple. Unfortunately, however, it did not seem a simplification, but rather quite the reverse. We may well suppose that the idea of wresting from the syllabary its secret of consonants and vowels, and giving to each consonantal sound a distinct sign, seemed a most cumbersome and embarrassing complication to the ancient scholars—that is to say, after the time arrived when any one gave such an idea expression. We can imagine them saying: "You will oblige us to use four signs instead of one to write such an elementary syllable as 'bard,' for example. Out upon such endless perplexity!" Nor is such a suggestion purely gratuitous, for it is an historical fact that the old syllabary continued to be used in Babylon hundreds of years after the alphabetical system had been introduced.[7] Custom is everything in establishing our prejudices. The Japanese to-day rebel against the introduction of an alphabet, thinking it ambiguous.

Yet, in the end, conservatism always yields, and so it was with opposition to the alphabet. Once the idea of the consonant had been firmly grasped, the old syllabary was doomed, though generations of time might be required to complete the obsequies—generations of time and the influence of a new nation. We have now to inquire how and by whom this advance was made.

THE ALPHABET ACHIEVED

We cannot believe that any nation could have vaulted to the final stage of the simple alphabetical writing without tracing the devious and difficult way of the pictograph and the syllabary. It is possible, however, for a cultivated nation to build upon the shoulders of its neighbors, and, profiting by the experience of others, to make sudden leaps upward and onward. And this is seemingly what happened in the final development of the art of writing. For while the Babylonians and Assyrians rested content with their elaborate syllabary, a nation on either side of them, geographically speaking, solved the problem, which they perhaps did not even recognize as a problem; wrested from their syllabary its secret of consonants and vowels, and by adopting an arbitrary sign for each consonantal sound, produced that most wonderful of human inventions, the alphabet.

The two nations credited with this wonderful achievement are the Phœnicians and the Persians. But it is not usually conceded that the two are entitled to anything like equal credit. The Persians, probably in the time of Cyrus the Great, used certain characters of the Babylonian script for the construction of an alphabet; but at this time the Phœnician alphabet had undoubtedly been in use for some centuries, and it is more than probable that the Persian borrowed his idea of an alphabet from a Phœnician source. And that, of course, makes all the difference. Granted the idea of an alphabet, it requires no great reach of constructive genius to supply a set of alphabetical characters; though even here, it may be added parenthetically, a study of the development of alphabets will show that mankind has all along had a characteristic propensity to copy rather than to invent.

Regarding the Persian alphabet-maker, then, as a copyist rather than a true inventor, it remains to turn attention to the Phœnician source whence, as is commonly believed, the original alphabet which became "the mother of all existing alphabets" came into being. It must be admitted at the outset that evidence for the Phœnician origin of this alphabet is traditional rather than demonstrative. The Phœnicians were the great traders of antiquity; undoubtedly they were largely responsible for the transmission of the alphabet from one part of the world to another, once it had been invented. Too much credit cannot be given them for this; and as the world always honors him who makes an idea fertile rather than the originator of the idea, there can be little injustice in continuing to speak of the Phœnicians as the inventors of the alphabet. But the actual facts of the case will probably never be known. For aught we know, it may have been some dreamy-eyed Israelite, some Babylonian philosopher, some Egyptian mystic, perhaps even some obscure Cretan, who gave to the hard-headed Phœnician trader this conception of a dismembered syllable with its all-essential, elemental, wonder-working consonant. But it is futile now to attempt even to surmise on such unfathomable details as these. Suffice it that the analysis was made; that one sign and no more was adopted for each consonantal sound of the Semitic tongue, and that the entire cumbersome mechanism of the Egyptian and Babylonian writing systems was rendered obsolescent. These systems did not yield at once, to be sure; all human experience would have been set at naught had they done so. They held their own, and much more than held their own, for many centuries. After the Phœnicians as a nation had ceased to have importance; after their original script had been endlessly modified by many alien nations; after the original alphabet had made the conquest of all civilized Europe and of far outlying portions of the Orient — the Egyptian and Babylonian scribes continued to indite their missives in the same old pictographs and syllables.

The inventive thinker must have been struck with amazement when, after making the fullest analysis of speech-sounds of which he was capable, he found himself supplied with only a score or so of symbols. Yet as regards the consonantal sounds he had exhausted the resources of the Semitic tongue. As to vowels, he scarcely considered them at all. It seemed to him sufficient to use one symbol for each consonantal sound. This reduced the hitherto complex mechanism of writing to so simple a system that the inventor must have regarded it with sheer delight. On the other hand, the conservative scholar doubtless thought it distinctly ambiguous. In truth, it must be admitted that the system was imperfect. It was a vast improvement on the old syllabary, but it had its drawbacks. Perhaps it had been made a bit too simple; certainly it should have had symbols for the vowel sounds as well as for the consonants. Nevertheless, the vowel-lacking alphabet seems to have taken the popular fancy, and to this day Semitic people have never supplied its deficiencies save with certain dots and points.

Peoples using the Aryan speech soon saw the defect, and the Greeks supplied symbols for several new sounds at a very early day.[8] But there the matter rested, and the alphabet has remained imperfect. For the purposes of the English language there should certainly have been added a dozen or more new characters. It is clear, for example, that, in the interest of explicitness, we should have a separate symbol for the vowel sound in each of the following syllables: bar, bay, bann, ball, to cite a single illustration.

There is, to be sure, a seemingly valid reason for not extending our alphabet, in the fact that in multiplying syllables it would be difficult to select characters at once easy to make and unambiguous. Moreover, the conservatives might point out, with telling effect, that the present alphabet has proved admirably effective for about three thousand years. Yet the fact that our dictionaries supply diacritical marks for some thirty vowels sounds to indicate the pronunciation of the words of our every-day speech, shows how we let memory and guessing do the work that might reasonably be demanded of a really complete alphabet. But, whatever its defects, the existing alphabet is a marvellous piece of mechanism, the result of thousands of years of intellectual effort. It is, perhaps without exception, the most stupendous invention of the human intellect within historical times—an achievement taking rank with such great prehistoric discoveries as the use of articulate speech, the making of a fire, and the invention of stone implements, of the wheel and axle, and of picture-writing. It made possible for the first time that education of the masses upon which all later progress of civilization was so largely to depend.

V

THE BEGINNINGS OF GREEK SCIENCE

HERODOTUS, the Father of History, tells us that once upon a time — which time, as the modern computator shows us, was about the year 590 B.C. —a war had risen between the Lydians and the Medes and continued five years. "In these years the Medes often discomfited the Lydians and the Lydians often discomfited the Medes (and among other things they fought a battle by night); and yet they still carried on the war with equally balanced fortitude. In the sixth year a battle took place in which it happened, when the fight had begun, that suddenly the day became night. And this change of the day Thales, the Milesian, had foretold to the Ionians, laying down as a limit this very year in which the change took place. The Lydians, however, and the Medes, when they saw that it had become night instead of day, ceased from their fighting and were much more eager, both of them, that peace should be made between them."

This memorable incident occurred while Alyattus, father of Crœsus, was king of the Lydians. The modern astronomer, reckoning backward, estimates this eclipse as occurring probably May 25th, 585 B.C. The date is important as fixing a mile-stone in the chronology of ancient history, but it is doubly memorable because it is the first recorded instance of a predicted eclipse. Herodotus, who tells the story, was not born until about one hundred years after the incident occurred, but time had not dimmed the fame of the man who had performed the necromantic feat of prophecy. Thales, the Milesian, thanks in part at least to this accomplishment, had been known in life as first on the list of the Seven Wise Men of Greece, and had passed into history as the father of Greek philosophy. We may add that he had even found wider popular fame through being named by Hippolytus, and then by Father Æsop as the philosopher who, intent on studying the heavens, fell into a well; "whereupon," says Hippolytus, "a maid-servant named Thratta laughed at him and said, 'In his search for things in the sky he does not see what is at his feet.'"

Such citations as these serve to bring vividly to mind the fact that we are entering a new epoch of thought. Hitherto our studies have been impersonal. Among Egyptians and Babylonians alike we have had to deal with classes of scientific records, but we have scarcely come across a single name. Now, however, we shall begin to find records of the work of individual investigators. In general, from now on, we shall be able to trace each great idea, if not to its originator, at least to some one man of genius who was prominent in bringing it before the world. The first of these vitalizers of thought, who stands out at the beginnings of Greek history, is this same Thales, of Miletus. His is not a very sharply defined personality as we look back upon it, and we can by no means be certain that all the discoveries which are ascribed to him are specifically his. Of his individuality as a man we know very little. It is not even quite certain as to where he was born; Miletus is usually accepted as his birthplace, but one tradition makes him by birth a Phenician. It is not at all in question, however, that by blood he was at least in part an Ionian Greek. It will be recalled that in the seventh century B.C., when Thales was born—and for a long time thereafter—the eastern shores of the Ægean Sea were quite as prominently the centre of Greek influence as was the peninsula of Greece itself. Not merely Thales, but his followers and disciples, Anaximander and Anaximenes, were born there. So also was Herodotus, the Father of History, not to extend the list. There is nothing anomalous, then, in the fact that Thales, the father of Greek thought, was born and passed his life on soil that was not geographically a part of Greece; but the fact has an important significance of another kind. Thanks to his environment, Thales was necessarily brought more or less in contact with Oriental ideas. There was close commercial contact between the land of his nativity and the great Babylonian capital off to the east, as also with Egypt. Doubtless this association was of influence in shaping the development of Thales's mind. Indeed, it was an accepted tradition throughout classical times that the Milesian philosopher had travelled in Egypt, and had there gained at least the rudiments of his knowledge of geometry. In the fullest sense, then, Thales may be regarded as representing a link in the chain of thought connecting the learning of the old Orient with the nascent scholarship of the new Occident. Occupying this position, it is fitting that the personality of Thales should partake somewhat of mystery; that the scene may not be shifted too suddenly from the vague, impersonal East to the individualism of Europe.

All of this, however, must not be taken as casting any doubt upon the existence of Thales as a real person. Even the dates of his life—640 to 546 B.C.—may be accepted as at least approximately trustworthy; and the specific discoveries ascribed to him illustrate equally well the stage of development of Greek thought, whether Thales himself or one of his immediate disciples were the discoverer. We have already mentioned the feat which was said to have given Thales his great reputation. That Thales was universally credited with having predicted the famous eclipse is beyond question. That he actually did predict it in any precise sense of the word is open to doubt. At all events, his prediction was not based upon any such precise knowledge as that of the modern astronomer. There is, indeed, only one way in which he could have foretold the eclipse, and that is through knowledge of the regular succession of preceding eclipses. But that knowledge implies access on the part of some one to long series of records of practical observations of the heavens. Such records, as we have seen, existed in Egypt and even more notably in Babylonia. That these records were the source of the information which established the reputation of Thales is an unavoidable inference. In other words, the magical prevision of the father of Greek thought was but a reflex of Oriental wisdom. Nevertheless, it sufficed to establish Thales as the father of Greek astronomy. In point of fact, his actual astronomical attainments would appear to have been meagre enough. There is nothing to show that he gained an inkling of the true character of the solar system. He did not even recognize the sphericity of the earth, but held, still following the Oriental authorities, that the world is a flat disk. Even his famous cosmogonic guess, according to which water is the essence of all things and the primordial element out of which the earth was developed, is but an elaboration of the Babylonian conception.

When we turn to the other field of thought with which the name of Thales is associated—namely, geometry—we again find evidence of the Oriental influence. The science of geometry, Herodotus assures us, was invented in Egypt. It was there an eminently practical science, being applied, as the name literally suggests, to the measurement of the earth's surface. Herodotus tells us that the Egyptians were obliged to cultivate the science because the periodical inundations washed away the boundary-lines between their farms. The primitive geometer, then, was a surveyor. The Egyptian records, as now revealed to us, show that the science had not been carried far in the land of its birth. The Egyptian geometer was able to measure irregular pieces of land only approximately. He never fully grasped the idea of the perpendicular as the true index of measurement for the triangle, but based his calculations upon measurements of the actual side of that figure. Nevertheless, he had learned to square the circle with a close approximation to the truth, and, in general, his measurement sufficed for all his practical needs. Just how much of the geometrical knowledge which added to the fame of Thales was borrowed directly from the Egyptians, and how much he actually created we cannot be sure. Nor is the question raised in disparagement of his genius. Receptivity is the first prerequisite to progressive thinking, and that Thales reached out after and imbibed portions of Oriental wisdom argues in itself for the creative character of his genius. Whether borrower or originator, however, Thales is credited with the expression of the following geometrical truths:

1. That the circle is bisected by its diameter.
2. That the angles at the base of an isosceles triangle are equal.
3. That when two straight lines cut each other the vertical opposite angles are equal.
4. That the angle in a semicircle is a right angle.
5. That one side and one acute angle of a right-angle triangle determine the other sides of the triangle.

It was by the application of the last of these principles that Thales is said to have performed the really notable feat of measuring the distance of a ship from the shore, his method being precisely the same in principle as that by which the guns are sighted on a modern man-of-war. Another practical demonstration which Thales was credited with making, and to which also his geometrical studies led him, was the measurement of any tall object, such as a pyramid or building or tree, by means of its shadow. The method, though simple enough, was ingenious. It consisted merely in observing the moment of the day when a perpendicular stick casts a shadow equal to its own length. Obviously the tree or monument would also cast a shadow equal to its own height at the same moment. It remains then but to measure the length of this shadow to determine the height of the object. Such feats as this evidence the practicality of the genius of Thales. They suggest that Greek science, guided by imagination, was starting on the high-road of observation. We are told that Thales conceived for the first time the geometry of lines, and that this, indeed, constituted his real advance upon the Egyptians. We are told also that he conceived the eclipse of the sun as a purely natural phenomenon, and that herein lay his advance upon the Chaldean point of view. But if this be true Thales was greatly in advance of his time, for it will be recalled that fully two hundred years later the Greeks under Nicias before Syracuse were so disconcerted by the appearance of an eclipse, which was interpreted as a direct omen and warning, that Nicias threw away the last opportunity to rescue his army. Thucydides, it is true, in recording this fact speaks disparagingly of the superstitious bent of the mind of Nicias, but Thucydides also was a man far in advance of his time.

All that we know of the psychology of Thales is summed up in the famous maxim, "Know thyself," a maxim which, taken in connection with the proven receptivity of the philosopher's mind, suggests to us a marvellously rounded personality.

The disciples or successors of Thales, Anaximander and Anaximenes, were credited with advancing knowledge through the invention or introduction of the sundial. We may be sure, however, that the gnomon, which is the rudimentary sundial, had been known and used from remote periods in the Orient, and the most that is probable is that Anaximander may have elaborated some special design, possibly the bowl-shaped sundial, through which the shadow of the gnomon would indicate the time. The same philosopher is said to have made the first sketch of a geographical map, but this again is a statement which modern researches have shown to be fallacious, since a Babylonian attempt at depicting the geography of the world is still preserved to us on a clay tablet. Anaximander may, however, have been the first Greek to make an attempt of this kind. Here again the influence of Babylonian science upon the germinating Western thought is suggested.

It is said that Anaximander departed from Thales's conception of the earth, and, it may be added, from the Babylonian conception also, in that he conceived it as a cylinder, or rather as a truncated cone, the upper end of which is the habitable portion. This conception is perhaps the first of these guesses through which the Greek mind attempted to explain the apparent fixity of the earth. To ask what supports the earth in space is most natural, but the answer given by Anaximander, like that more familiar Greek solution which transformed the cone, or cylinder, into the giant Atlas, is but another illustration of that substitution of unwarranted inference for scientific induction which we have already so often pointed out as characteristic of the primitive stages of thought.

Anaximander held at least one theory which, as vouched for by various copyists and commentators, entitles him to be considered perhaps the first teacher of the idea of organic evolution. According to this idea, man developed from a fishlike ancestor, "growing up as sharks do until able to help himself and then coming forth on dry land."[1] The thought here expressed finds its germ, perhaps, in the Babylonian conception that everything came forth from a chaos of waters. Yet the fact that the thought of Anaximander has come down to posterity through such various channels suggests that the Greek thinker had got far enough away from the Oriental conception to make his view seem to his contemporaries a novel and individual one. Indeed, nothing we know of the Oriental line of thought conveys any suggestion of the idea of transformation of species, whereas that idea is distinctly formulated in the traditional views of Anaximander.

VI

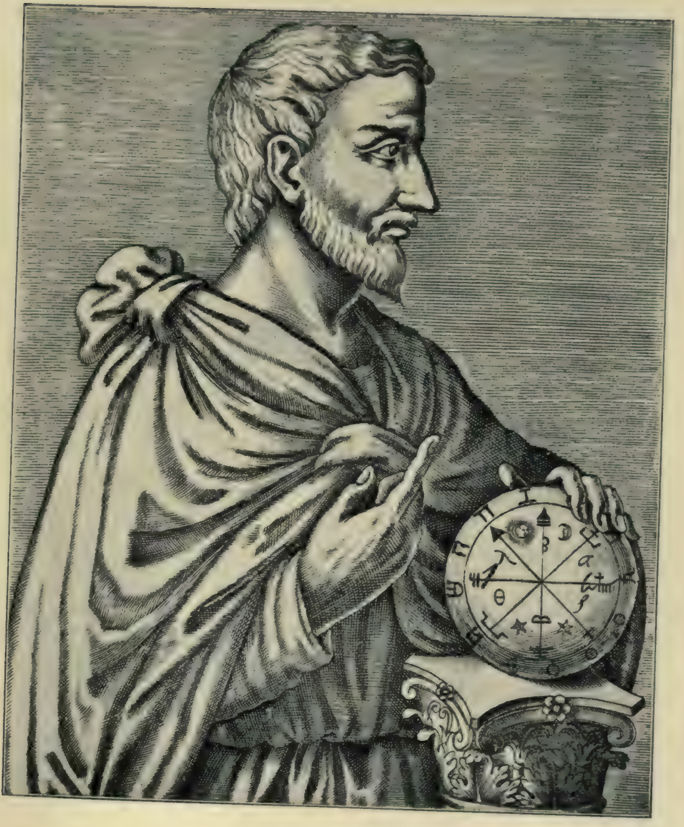
THE EARLY GREEK PHILOSOPHERS IN ITALY

DIOGENES LAERTIUS tells a story about a youth who, clad in a purple toga, entered the arena at the Olympian games and asked to compete with the other youths in boxing. He was derisively denied admission, presumably because he was beyond the legitimate age for juvenile contestants. Nothing daunted, the youth entered the lists of men, and turned the laugh on his critics by coming off victor. The youth who performed this feat was named Pythagoras. He was the same man, if we may credit the story, who afterwards migrated to Italy and became the founder of the famous Crotonian School of Philosophy; the man who developed the religion of the Orphic mysteries; who conceived the idea of the music of the spheres; who promulgated the doctrine of metempsychosis; who first, perhaps, of all men clearly conceived the notion that this world on which we live is a ball which moves in space and which may be habitable on every side.

A strange development that for a stripling pugilist. But we must not forget that in the Greek world athletics held a peculiar place. The chief winner of Olympian games gave his name to an epoch (the ensuing Olympiad of four years), and was honored almost before all others in the land. A sound mind in a sound body was the motto of the day. To excel in feats of strength and dexterity was an accomplishment that even a philosopher need not scorn. It will be recalled that Æschylus distinguished himself at the battle of Marathon; that Thucydides, the greatest of Greek historians, was a general in the Peloponnesian War; that Xenophon, the pupil and biographer of Socrates, was chiefly famed for having led the Ten Thousand in the memorable campaign of Cyrus the Younger; that Plato himself was credited with having shown great aptitude in early life as a wrestler. If, then, Pythagoras the philosopher was really the Pythagoras who won the boxing contest, we may suppose that in looking back upon this athletic feat from the heights of his priesthood—for he came to be almost deified—he regarded it not as an indiscretion of his youth, but as one of the greatest achievements of his life. Not unlikely he recalled with pride that he was credited with being no less an innovator in athletics than in philosophy. At all events, tradition credits him with the invention of "scientific" boxing. Was it he, perhaps, who taught the Greeks to strike a rising and swinging blow from the hip, as depicted in the famous metopes of the Parthenon? If so, the innovation of Pythagoras was as little heeded in this regard in a subsequent age as was his theory of the motion of the earth; for to strike a swinging blow from the hip, rather than from the shoulder, is a trick which the pugilist learned anew in our own day.

But enough of pugilism and of what, at best, is a doubtful tradition. Our concern is with another "science" than that of the arena. We must follow the purple-robed victor to Italy—if, indeed, we be not over-credulous in accepting the tradition—and learn of triumphs of a different kind that have placed the name of Pythagoras high on the list of the fathers of Grecian thought. To Italy? Yes, to the western limits of the Greek world. Here it was, beyond the confines of actual Greek territory, that Hellenic thought found its second home, its first home being, as we have seen, in Asia Minor. Pythagoras, indeed, to whom we have just been introduced, was born on the island of Samos, which lies near the coast of Asia Minor, but he probably migrated at an early day to Crotona, in Italy. There he lived, taught, and developed his philosophy until rather late in life, when, having incurred the displeasure of his fellow-citizens, he suffered the not unusual penalty of banishment.

Of the three other great Italic leaders of thought of the early period, Xenophanes came rather late in life to Elea and founded the famous Eleatic School, of which Parmenides became the most distinguished ornament. These two were Ionians, and they lived in the sixth century before our era. Empedocles, the Sicilian, was of Doric origin. He lived about the middle of the fifth century B.C., at a time, therefore, when Athens had attained a position of chief glory among the Greek states; but there is no evidence that Empedocles ever visited that city, though it was rumored that he returned to the Peloponnesus to die. The other great Italic philosophers just named, living, as we have seen, in the previous century, can scarcely have thought of Athens as a centre of Greek thought. Indeed, the very fact that these men lived in Italy made that peninsula,



PYTHAGORAS

(From an old print.)

rather than the mother-land of Greece, the centre of Hellenic influence. But all these men, it must constantly be borne in mind, were Greeks by birth and language, fully recognized as such in their own time and by posterity. Yet the fact that they lived in a land which was at no time a part of the geographical territory of Greece must not be forgotten. They, or their ancestors of recent generations, had been pioneers among those venturesome colonists who reached out into distant portions of the world, and made homes for themselves in much the same spirit in which colonists from Europe began to populate America some two thousand years later. In general, colonists from the different parts of Greece localized themselves somewhat definitely in their new homes; yet there must naturally have been a good deal of commingling among the various families of pioneers, and, to a certain extent, a mingling also with the earlier inhabitants of the country. This racial mingling, combined with the well-known vitalizing influence of the pioneer life, led, we may suppose, to a more rapid and more varied development than occurred among the home-staying Greeks. In proof of this, witness the remarkable schools of philosophy which, as we have seen, were thus developed at the confines of the Greek world, and which were presently to invade and, as it were, take by storm the mother-country itself.

As to the personality of these pioneer philosophers of the West, our knowledge is for the most part more or less traditional. What has been said of Thales may be repeated, in the main, regarding Pythagoras, Parmenides, and Empedocles. That they were real persons is not at all in question, but much that is merely traditional has come to be associated with their names. Pythagoras was the senior, and doubtless his ideas may have influenced the others more or less, though each is usually spoken of as the founder of an independent school. Much confusion has all along existed, however, as to the precise ideas which were to be ascribed to each of the leaders. Numberless commentators, indeed, have endeavored to pick out from among the traditions of antiquity, aided by such fragments of the writing of the philosophers as have come down to us, the particular ideas that characterized each thinker, and to weave these ideas into systems. But such efforts, notwithstanding the mental energy that has been expended upon them, were, of necessity, futile, since, in the first place, the ancient philosophers themselves did not specialize and systematize their ideas according to modern notions, and, in the second place, the records of their individual teachings have been too scantily preserved to serve for the purpose of classification. It is freely admitted that fable has woven an impenetrable mesh of contradictions about the personalities of these ancient thinkers, and it would be folly to hope that this same artificer had been less busy with their beliefs and theories. When one reads that Pythagoras advocated an exclusively vegetable diet, yet that he was the first to train athletes on meat diet; that he sacrificed only inanimate things, yet that he offered up a hundred oxen in honor of his great discovery regarding the sides of a triangle, and such like inconsistencies in the same biography, one gains a realizing sense of the extent to which diverse traditions enter into the story as it has come down to us. And yet we must reflect that most men change their opinions in the course of a long lifetime, and that the antagonistic reports may both be true.

True or false, these fables have an abiding interest, since they prove the unique and extraordinary character of the personality about which they are woven. The alleged witticisms of a Whistler, in our own day, were doubtless, for the most part, quite unknown to Whistler himself, yet they never would have been ascribed to him were they not akin to witticisms that he did originate—were they not, in short, typical expressions of his personality. And so of the heroes of the past. "It is no ordinary man," said George Henry Lewes, speaking of Pythagoras, "whom fable exalts into the poetic region. Whenever you find romantic or miraculous deeds attributed, be certain that the hero was great enough to maintain the weight of the crown of this fabulous glory."[1] We may not doubt, then, that Pythagoras, Parmenides, and Empedocles, with whose names fable was so busy throughout antiquity, were men of extraordinary personality. We are here chiefly concerned, however, neither with the personality of the man nor yet with the precise doctrines which each one of them taught. A knowledge of the latter would be interesting were it attainable, but in the confused state of the reports that have come down to us we cannot hope to be able to ascribe each idea with precision to its proper source. At best we can merely outline, even here not too precisely, the scientific doctrines which the Italic philosophers as a whole seem to have advocated.

First and foremost, there is the doctrine that the earth is a sphere. Pythagoras is said to have been the first advocate of this theory; but, unfortunately, it is reported also that Parmenides was its author. This rivalship for the discovery of an important truth we shall see repeated over and over in more recent times. Could we know the whole truth, it would perhaps appear that the idea of the sphericity of the earth was originated long before the time of the Greek philosophers. But it must be admitted that there is no record of any sort to give tangible support to such an assumption. So far as we can ascertain, no Egyptian or Babylonian astronomer ever grasped the wonderful conception that the earth is round. That the Italic Greeks should have conceived that idea was perhaps not so much because they were astronomers as because they were practical geographers and geometers. Pythagoras, as we have noted, was born at Samos, and, therefore, made a relatively long sea voyage in passing to Italy. Now, as every one knows, the most simple and tangible demonstration of the convexity of the earth's surface is furnished by observation of an approaching ship at sea. On a clear day a keen eye may discern the mast and sails rising gradually above the horizon, to be followed in due course by the hull. Similarly, on approaching the shore, high objects become visible before those that lie nearer the water. It is at least a plausible supposition that Pythagoras may have made such observations as these during the voyage in question, and that therein may lie the germ of that wonderful conception of the world as a sphere.

To what extent further proof, based on the fact that the earth's shadow when the moon is eclipsed is always convex, may have been known to Pythagoras we cannot say. There is no proof that any of the Italic philosophers made extensive records of astronomical observations as did the Egyptians and Babylonians; but we must constantly recall that the writings of classical antiquity have been almost altogether destroyed. The absence of astronomical records is, therefore, no proof that such records never existed. Pythagoras, it should be said, is reported to have travelled in Egypt, and he must there have gained an inkling of astronomical methods. Indeed, he speaks of himself specifically, in a letter quoted by Diogenes, as one who is accustomed to study astronomy. Yet a later sentence of the letter, which asserts that the philosopher is not always occupied about speculations of his own fancy, suggesting, as it does, the dreamer rather than the observer, gives us probably a truer glimpse into the philosopher's mind. There is, indeed, reason to suppose that the doctrine of the sphericity of the earth appealed to Pythagoras chiefly because it accorded with his conception that the sphere is the most perfect solid, just as the circle is the most perfect plane surface. Be that as it may, the fact remains that we have here, as far as we can trace its origin, the first expression of the scientific theory that the earth is round. Had the Italic philosophers accomplished nothing more than this, their accomplishment would none the less mark an epoch in the progress of thought.

That Pythagoras was an observer of the heavens is further evidenced by the statement made by Diogenes, on the authority of Parmenides, that Pythagoras was the first person who discovered or asserted the identity of Hesperus and Lucifer—that is to say, of the morning and the evening star. This was really a remarkable discovery, and one that was no doubt instrumental later on in determining that theory of the mechanics of the heavens which we shall see elaborated presently. To have made such a discovery argues again for the practicality of the mind of Pythagoras. His, indeed, would seem to have been a mind in which practical common-sense was strangely blended with the capacity for wide and imaginative generalization. As further evidence of his practicality, it is asserted that he was the first person who introduced measures and weights among the Greeks, this assertion being made on the authority of Aristoxenus. It will be observed that he is said to have introduced, not to have invented, weights and measures, a statement which suggests a knowledge on the part of the Greeks that weights and measures were previously employed in Egypt and Babylonia.

The mind that could conceive the world as a sphere and that interested itself in weights and measures was, obviously, a mind of the visualizing type. It is characteristic of this type of mind to be interested in the tangibilities of geometry, hence it is not surprising to be told that Pythagoras "carried that science to perfection." The most famous discovery of Pythagoras in this field was that the square of the hypotenuse of a right-angled triangle is equal to the squares of the other sides of the triangle. We have already noted the fable that his enthusiasm over this discovery led him to sacrifice a hecatomb. Doubtless the story is apocryphal, but doubtless, also, it expresses the truth as to the fervid joy with which the philosopher must have contemplated the results of his creative imagination.

No line alleged to have been written by Pythagoras has come down to us. We are told that he refrained from publishing his doctrines, except by word of mouth. "The Lucanians and the Peucetians, and the Messapians and the Romans," we are assured, "flocked around him, coming with eagerness to hear his discourses; no fewer than six hundred came to him every night; and if any one of them had ever been permitted to see the master, they wrote of it to their friends as if they had gained some great advantage." Nevertheless, we are assured that until the time of Philolaus no doctrines of Pythagoras were ever published, to which statement it is added that "when the three celebrated books were published, Plato wrote to have them purchased for him for a hundred minas."[2] But if such books existed, they are lost to the modern world, and we are obliged to accept the assertions of relatively late writers as to the theories of the great Crotonian.

Perhaps we cannot do better than quote at length from an important summary of the remaining doctrines of Pythagoras, which Diogenes himself quoted from the work of a predecessor.[3] Despite its somewhat inchoate character, this summary is a most remarkable one, as a brief analysis of its contents will show. It should be explained that Alexander (whose work is now lost) is said to have found these dogmas set down in the commentaries of Pythagoras. If this assertion be accepted, we are brought one step nearer the philosopher himself. The summary is as follows:

"That the monad was the beginning of everything. From the monad proceeds an indefinite duad, which is subordinate to the monad as to its cause. That from the monad and the indefinite duad proceed numbers. And from numbers signs. And from these last, lines of which plane figures consist. And from plane figures are derived solid bodies. And from solid bodies sensible bodies, of which last there are four elements—fire, water, earth, and air. And that the world, which is indued with life and intellect, and which is of a spherical figure, having the earth, which is also spherical, and inhabited all over in its centre,[4] results from a combination of these elements, and derives its motion from them; and also that there are antipodes, and that what is below, as respects us, is above in respect of them.

"He also taught that light and darkness, and cold and heat, and dryness and moisture, were equally divided in the world; and that while heat was predominant it was summer; while cold had the mastery, it was winter; when dryness prevailed, it was spring; and when moisture preponderated, winter. And while all these qualities were on a level, then was the loveliest season of the year; of which the flourishing spring was the wholesome period, and the season of autumn the most pernicious one. Of the day, he said that the flourishing period was the morning, and the fading one the evening; on which account that also was the least healthy time.

"Another of his theories was that the air around the earth was immovable and pregnant with disease, and that everything in it was mortal; but that the upper air was in perpetual motion, and pure and salubrious, and that everything in that was immortal, and on that account divine. And that the sun and the moon and the stars were all gods; for in them the warm principle predominates which is the cause of life. And that the moon derives its light from the sun. And that there is a relationship between men and the gods, because men partake of the divine principle; on which account, also, God exercises his providence for our advantage. Also, that Fate is the cause of the arrangement of the world both generally and particularly. Moreover, that a ray from the sun penetrated both the cold æther and the dense æther; and they call the air the *cold æther*, and the sea and moisture they call the *dense æther*. And this ray descends into the depths, and in this way vivifies everything. And everything which partakes of the principle of heat lives, on which account, also, plants are animated beings; but that all living things have not necessarily souls. And that the soul is a something torn off from the æther, both warm and cold, from its partaking of the cold æther. And that the soul is something different from life. Also, that it is immortal, because that from which it has been detached is immortal.

"Also, that animals are born from one another by seeds, and that it is impossible for there to be any spontaneous production by the earth. And that seed is a drop from the brain which contains in itself a warm vapor; and that when this is applied to the womb it transmits virtue and moisture and blood from the brain, from which flesh and sinews and bones and hair and the whole body are produced. And from the vapor is produced the soul, and also sensation. And that the infant first becomes a solid body at the end of forty days; but, according to the principles of harmony, it is not perfect till seven, or perhaps nine, or at most ten months, and then it is brought forth. And that it contains in itself all the principles of life, which are all connected together, and by their union and combination form a harmonious whole, each of them developing itself at the appointed time.

"The senses in general, and especially the sight, are a vapor of excessive warmth, and on this account a man is said to see through air and through water. For the hot principle is opposed by the cold one; since, if the vapor in the eyes were cold, it would have the same temperature as the air, and so would be dissipated. As it is, in some passages he calls the eyes the gates of the sun; and he speaks in a similar manner of hearing and of the other senses.

"He also says that the soul of man is divided into three parts: into intuition and reason and mind, and that the first and last divisions are found also in other animals, but that the middle one, reason, is only found in man. And that the chief abode of the soul is in those parts of the body which are between the heart and the brain. And that that portion of it which is in the heart is the mind; but that deliberation and reason reside in the brain.

"Moreover, that the senses are drops from them;

and that the reasoning sense is immortal, but the others are mortal. And that the soul is nourished by the blood; and that reasons are the winds of the soul. That it is invisible, and so are its reasons, since the æther itself is invisible. That the links of the soul are the veins and the arteries and the nerves. But that when it is vigorous, and is by itself in a quiescent state, then its links are words and actions. That when it is cast forth upon the earth it wanders about, resembling the body. Moreover, that Mercury is the steward of the souls, and that on this account he has the name of Conductor, and Commercial, and Infernal, since it is he who conducts the souls from their bodies, and from earth and sea; and that he conducts the pure souls to the highest region, and that he does not allow the impure ones to approach them, nor to come near one another, but commits them to be bound in indissoluble fetters by the Furies. The Pythagoreans also assert that the whole air is full of souls, and that these are those which are accounted dæmons and heroes. Also, that it is by them that dreams are sent among men, and also the tokens of disease and health; these last, too, being sent not only to men, but to sheep also, and other cattle. Also that it is they who are concerned with purifications and expiations and all kinds of divination and oracular predictions, and things of that kind."[5]

A brief consideration of this summary of the doctrines of Pythagoras will show that it at least outlines a most extraordinary variety of scientific ideas. (1) There is suggested a theory of monads and the conception of the development from simple to more complex bodies, passing through the stages of lines, plain figures, and solids to sensible bodies. (2) The doctrine of the four elements—fire, water, earth, and air—as the basis of all organisms is put forward. (3) The idea, not merely of the sphericity of the earth, but an explicit conception of the antipodes, is expressed. (4) A conception of the sanitary influence of the air is clearly expressed. (5) An idea of the problems of generation and heredity is shown, together with a distinct disavowal of the doctrine of spontaneous generation—a doctrine which, it may be added, remained in vogue, nevertheless, for some twenty-four hundred years after the time of Pythagoras. (6) A remarkable analysis of mind is made, and a distinction between animal minds and the human mind is based on this analysis. The physiological doctrine that the heart is the organ of one department of mind is offset by the clear statement that the remaining factors of mind reside in the brain. This early recognition of brain as the organ of mind must not be forgotten in our later studies. It should be recalled, however, that a Crotonian physician, Alemaean, a younger contemporary of Pythagoras, is also credited with the same theory. (7) A knowledge of anatomy is at least vaguely foreshadowed in the assertion that veins, arteries, and nerves are the links of the soul. In this connection it should be recalled that Pythagoras was a practical physician.

As against these scientific doctrines, however, some of them being at least remarkable guesses at the truth, attention must be called to the concluding paragraph of our quotation, in which the old familiar dæmonology is outlined, quite after the Oriental fashion. We shall have occasion to say more as to this phase of the subject later on. Meantime, before leaving Pythagoras, let us note that his practical studies of humanity led him to assert the doctrine that "the property of friends is common, and that friendship is equality." His disciples, we are told, used to put all their possessions together in one store and use them in common. Here, then, seemingly, is the doctrine of communism put to the test of experiment at this early day. If it seem that reference to this carries us beyond the bounds of science, it may be replied that questions such as this will not lie beyond the bounds of the science of the near future.

XENOPHANES AND PARMENIDES

There is a whimsical tale about Pythagoras, according to which the philosopher was wont to declare that in an earlier state he had visited Hades, and had there seen Homer and Hesiod tortured because of the absurd things they had said about the gods. Apocryphal or otherwise, the tale suggests that Pythagoras was an agnostic as regards the current Greek religion of his time. The same thing is perhaps true of most of the great thinkers of this earliest period. But one among them was remembered in later times as having had a peculiar aversion to the anthropomorphic conceptions of his fellows. This was Xenophanes, who was born at Colophon probably about the year 580 B.C., and who, after a life of wandering, settled finally in Italy and became the founder of the so-called Eleatic School.

A few fragments of the philosophical poem in which

Xenophanes expressed his views have come down to us, and these fragments include a tolerably definite avowal of his faith. "God is one supreme among gods and men, and not like mortals in body or in mind," says Xenophanes. Again he asserts that "mortals suppose that the gods are born (as they themselves are), that they wear man's clothing and have human voice and body; but," he continues, "if cattle or lions had hands so as to paint with their hands and produce works of art as men do, they would paint their gods and give them bodies in form like their own—horses like horses, cattle like cattle." Elsewhere he says, with great acumen: "There has not been a man, nor will there be, who knows distinctly what I say about the gods or in regard to all things. For even if one chance for the most part to say what is true, still he would not know; but every one thinks that he knows."[6]

In the same spirit Xenophanes speaks of the battles of Titans, of giants, and of centaurs as "fictions of former ages." All this tells of the questioning spirit which distinguishes the scientific investigator. Precisely whither this spirit led him we do not know, but the writers of a later time have preserved a tradition regarding a belief of Xenophanes that perhaps entitles him to be considered the father of geology. Thus Hippolytus records that Xenophanes studied the fossils to be found in quarries, and drew from their observation remarkable conclusions. His words are as follows: "Xenophanes believes that once the earth was mingled with the sea, but in the course of time it became freed from moisture; and his proofs are such as these: that shells are found in the midst of the land and among the mountains, that in the quarries of Syracuse the imprints of a fish and of seals had been found, and in Paros the imprint of an anchovy at some depth in the stone, and in Melite shallow impressions of all sorts of sea products. He says that these imprints were made when everything long ago was covered with mud, and then the imprint dried in the mud. Further, he says that all men will be destroyed when the earth sinks into the sea and becomes mud, and that the race will begin anew from the beginning; and this transformation takes place for all worlds."[7] Here, then, we see this earliest of paleontologists studying the fossil-bearing strata of the earth, and drawing from his observations a marvellously scientific induction. Almost two thousand years later another famous citizen of Italy, Leonardo da Vinci, was independently to think out similar conclusions from like observations. But not until the nineteenth century of our era, some twenty-four hundred years after the time of Xenophanes, was the old Greek's doctrine to be accepted by the scientific world. The ideas of Xenophanes were known to his contemporaries and, as we see, quoted for a few centuries by his successors, then they were ignored or quite forgotten; and if any philosopher of an ensuing age before the time of Leonardo championed a like rational explanation of the fossils, we have no record of the fact. The geological doctrine of Xenophanes, then, must be listed among those remarkable Greek anticipations of nineteenth-century science which suffered almost total eclipse in the intervening centuries.

Among the pupils of Xenophanes was Parmenides, the thinker who was destined to carry on the work of his master along the same scientific lines, though at the same time mingling his scientific conceptions with the mysticism of the poet. We have already had occasion to mention that Parmenides championed the idea that the earth is round; noting also that doubts exist as to whether he or Pythagoras originated this doctrine. No explicit answer to this question can possibly be hoped for. It seems clear, however, that for a long time the Italic School, to which both these philosophers belonged, had a monopoly of the belief in question. Parmenides, like Pythagoras, is credited with having believed in the motion of the earth, though the evidence furnished by the writings of the philosopher himself is not as demonstrative as one could wish. Unfortunately, the copyists of a later age were more concerned with metaphysical speculations than with more tangible things. But as far as the fragmentary references to the ideas of Parmenides may be accepted, they do not support the idea of the earth's motion. Indeed, Parmenides is made to say explicitly, in preserved fragments, that "the world is immovable, limited, and spheroidal in form."[8]

Nevertheless, some modern interpreters have found an opposite meaning in Parmenides. Thus Ritter interprets him as supposing "that the earth is in the centre spherical, and maintained in rotary motion by its equiponderance; around it lie certain rings, the highest composed of the rare element fire, the next lower a compound of light and darkness, and lowest of all one wholly of night, which probably indicated to his mind the surface of the earth, the centre of which again he probably considered to be fire."[9] But this, like too many interpretations of ancient thought, appears to read into the fragments ideas which the words themselves do not warrant. There seems no reason to doubt, however, that Parmenides actually held the doctrine of the earth's sphericity. Another glimpse of his astronomical doctrines is furnished us by a fragment which tells us that he conceived the morning and the evening stars to be the same, a doctrine which, as we have seen, was ascribed also to Pythagoras. Indeed, we may repeat that it is quite impossible to distinguish between the astronomical doctrines of these two philosophers.

The poem of Parmenides in which the cosmogonic speculations occur treats also of the origin of man. The author seems to have had a clear conception that intelligence depends on bodily organism, and that the more elaborately developed the organism the higher the intelligence. But in the interpretation of this thought we are hampered by the characteristic vagueness of expression, which may best be evidenced by putting before the reader two English translations of the same stanza. Here is Ritter's rendering, as made into English by his translator, Morrison:

"For exactly as each has the state of his limbs many-jointed,
So invariably stands it with men in their mind and their reason;
For the system of limbs is that which thinketh in mankind
Alike in all and in each: for thought is the fulness."[10]

The same stanza is given thus by George Henry Lewes:

"Such as to each man is the nature of his many-jointed limbs,
Such also is the intelligence of each man; for it is

> The nature of limbs (organization) which thinketh in men,
> Both in one and in all; for the highest degree of organization gives the highest degree of thought."[11]

Here it will be observed that there is virtual agreement between the translators except as to the last clause, but that clause is most essential. The Greek phrase is **τὸ γὰρ πλέον ἐστὶ νόημα.** Ritter, it will be observed, renders this, "for thought is the fulness." Lewes paraphrases it, "for the highest degree of organization gives the highest degree of thought." The difference is intentional, since Lewes himself criticises the translation of Ritter. Ritter's translation is certainly the more literal, but the fact that such diversity is possible suggests one of the chief elements of uncertainty that hamper our interpretation of the thought of antiquity. Unfortunately, the mind of the commentator has usually been directed towards such subtleties, rather than towards the expression of precise knowledge. Hence it is that the philosophers of Greece are usually thought of as mere dreamers, and that their true status as scientific discoverers is so often overlooked. With these intangibilities we have no present concern beyond this bare mention; for us it suffices to gain as clear an idea as we may of the really scientific conceptions of these thinkers, leaving the subtleties of their deductive reasoning for the most part untouched.

EMPEDOCLES

The latest of the important pre-Socratic philosophers of the Italic school was Empedocles, who was born about 494 B.C. and lived to the age of sixty. These dates make Empedocles strictly contemporary with Anaxagoras, a fact which we shall do well to bear in mind when we come to consider the latter's philosophy in the succeeding chapter. Like Pythagoras, Empedocles is an imposing figure. Indeed, there is much of similarity between the personalities, as between the doctrines, of the two men. Empedocles, like Pythagoras, was a physician; like him also he was the founder of a cult. As statesman, prophet, physicist, physician, reformer, and poet he showed a versatility that, coupled with profundity, marks the highest genius. In point of versatility we shall perhaps hardly find his equal at a later day—unless, indeed, an exception be made of Eratosthenes. The myths that have grown about the name of Empedocles show that he was a remarkable personality. He is said to have been an awe-inspiring figure, clothing himself in Oriental splendor and moving among mankind as a superior being. Tradition has it that he threw himself into the crater of a volcano that his otherwise unexplained disappearance might lead his disciples to believe that he had been miraculously translated; but tradition goes on to say that one of the brazen slippers of the philosopher was thrown up by the volcano, thus revealing his subterfuge. Another tradition of far more credible aspect asserts that Empedocles retreated from Italy, returning to the home of his fathers in Peloponnesus to die there obscurely. It seems odd that the facts regarding the death of so great a man, at so comparatively late a period, should be obscure; but this, perhaps, is in keeping with the personality of the man himself. His disciples would hesitate to ascribe a merely natural death to so inspired a prophet.

Empedocles appears to have been at once an observer and a dreamer. He is credited with noting that the pressure of air will sustain the weight of water in an inverted tube; with divining, without the possibility of proof, that light has actual motion in space; and with asserting that centrifugal motion must keep the heavens from falling. He is credited with a great sanitary feat in the draining of a marsh, and his knowledge of medicine was held to be supernatural. Fortunately, some fragments of the writings of Empedocles have come down to us, enabling us to judge at first hand as to part of his doctrines; while still more is known through the references made to him by Plato, Aristotle, and other commentators. Empedocles was a poet whose verses stood the test of criticism. In this regard he is in a like position with Parmenides; but in neither case are the preserved fragments sufficient to enable us fully to estimate their author's scientific attainments. Philosophical writings are obscure enough at the best, and they perforce become doubly so when expressed in verse. Yet there are certain passages of Empedocles that are unequivocal and full of interest. Perhaps the most important conception which the works of Empedocles reveal to us is the denial of anthropomorphism as applied to deity. We have seen how early the anthropomorphic conception was developed and how closely it was all along clung to; to shake the mind free from it then was a remarkable feat, in accomplishing which Empedocles took a long step in the direction of rationalism. His conception is paralleled by that of another physician, Alcmæon, of Proton, who contended that man's ideas of the gods amounted to mere suppositions at the very most. A rationalistic or sceptical tendency has been the accompaniment of medical training in all ages.

The words in which Empedocles expresses his conception of deity have been preserved and are well worth quoting: "It is not impossible," he says, "to draw near (to god) even with the eyes or to take hold of him with our hands, which in truth is the best highway of persuasion in the mind of man; for he has no human head fitted to a body, nor do two shoots branch out from the trunk, nor has he feet, nor swift legs, nor hairy parts, but he is sacred and ineffable mind alone, darting through the whole world with swift thoughts." [12]

How far Empedocles carried his denial of anthropomorphism is illustrated by a reference of Aristotle, who asserts "that Empedocles regards god as most lacking in the power of perception; for he alone does not know one of the elements, Strife (hence), of perishable things." It is difficult to avoid the feeling that Empedocles here approaches the modern philosophical conception that God, however postulated as immutable, must also be postulated as unconscious, since intelligence, as we know it, is dependent upon the transmutations of matter. But to urge this thought would be to yield to that philosophizing tendency which has been the bane of interpretation as applied to the ancient thinkers.

Considering for a moment the more tangible accomplishments of Empedocles, we find it alleged that one of his "miracles" consisted of the preservation of a dead body without putrefaction for some weeks after death. We may assume from this that he had gained in some way a knowledge of embalming. As he was notoriously fond of experiment, and as the body in question (assuming for the moment the authenticity of the legend) must have been preserved without disfigurement, it is conceivable even that he had hit upon the idea of injecting the arteries. This, of course, is pure conjecture; yet it finds a certain warrant, both in the fact that the words of Pythagoras lead us to believe that the arteries were known and studied, and in the fact that Empedocles' own words reveal him also as a student of the vascular system. Thus Plutarch cites Empedocles as believing "that the ruling part is not in the head or in the breast, but in the blood; wherefore in whatever part of the body the more of this is spread in that part men excel."[13] And Empedocles' own words, as preserved by Stobæus, assert "(the heart) lies in seas of blood which dart in opposite directions, and there most of all intelligence centres for men; for blood about the heart is intelligence in the case of man." All this implies a really remarkable appreciation of the dependence of vital activities upon the blood.

This correct physiological conception, however, was by no means the most remarkable of the ideas to which Empedocles was led by his anatomical studies. His greatest accomplishment was to have conceived and clearly expressed an idea which the modern evolutionist connotes when he speaks of homologous parts—an idea which found a famous modern expositor in Goethe, as we shall see when we come to deal with eighteenth-century science. Empedocles expresses the idea in these words: "Hair, and leaves, and thick feathers of birds, are the same thing in origin, and reptile scales too on strong limbs. But on hedgehogs sharp-pointed hair bristles on their backs."[14] That the idea of transmutation of parts, as well as of mere homology, was in mind is evidenced by a very remarkable sentence in which Aristotle asserts, "Empedocles says that fingernails rise from sinew from hardening." Nor is this quite all, for surely we find the germ of the Lamarckian conception of evolution through the transmission of acquired characters in the assertion that "many characteristics appear in animals because it happened to be thus in their birth, as that they have such a spine because they happen to be descended from one that bent itself backward."[15] Aristotle, in quoting this remark, asserts, with the dogmatism which characterizes the philosophical commentators of every age, that "Empedocles is wrong," in making this assertion; but Lamarck, who lived twenty-three hundred years after Empedocles, is famous in the history of the doctrine of evolution for elaborating this very idea.

It is fair to add, however, that the dreamings of Empedocles regarding the origin of living organisms led him to some conceptions that were much less luminous. On occasion, Empedocles the poet got the better of Empedocles the scientist, and we are presented with a conception of creation as grotesque as that which delighted the readers of *Paradise Lost* at a later day. Empedocles assures us that "many heads grow up without necks, and arms were wandering about, necks bereft of shoulders, and eyes roamed about alone with no foreheads."[16] This chaotic condition, so the poet dreamed, led to the union of many incongruous parts, producing "creatures with double faces, offspring of oxen with human faces, and children of men with oxen heads." But out of this chaos came, finally, we are led to infer, a harmonious aggregation of parts, producing ultimately the perfected organisms that we see. Unfortunately the preserved portions of the writings of Empedocles do not enlighten us as to the precise way in which final evolution was supposed to be effected; although the idea of endless experimentation until natural selection resulted in survival of the fittest seems not far afield from certain of the poetical assertions. Thus: "As divinity was mingled yet more with divinity, these things (the various members) kept coming together in whatever way each might chance." Again: "At one time all the limbs which form the body united into one by love grew vigorously in the prime of life; but yet at another time, separated by evil Strife, they wander each in different directions along the breakers of the sea of life. Just so is it with plants, and with fishes dwelling in watery halls, and beasts whose lair is in the mountains, and birds borne on wings."[17]

All this is poetry rather than science, yet such imaginings could come only to one who was groping towards what we moderns should term an evolutionary conception of the origins of organic life; and however grotesque some of these expressions may appear, it must be admitted that the morphological ideas of Empedocles, as above quoted, give the Sicilian philosopher a secure place among the anticipators of the modern evolutionist.

VII

GREEK SCIENCE IN THE EARLY ATTIC PERIOD

WE have travelled rather far in our study of Greek science, and yet we have not until now come to Greece itself. And even now, the men whose names we are to consider were, for the most part, born in outlying portions of the empire; they differed from the others we have considered only in the fact that they were drawn presently to the capital. The change is due to a most interesting sequence of historical events. In the day when Thales and his immediate successors taught in Miletus, when the great men of the Italic school were in their prime, there was no single undisputed centre of Greek influence. The Greeks were a disorganized company of petty nations, welded together chiefly by unity of speech; but now, early in the fifth century B.C., occurred that famous attack upon the Western world by the Persians under Darius and his son and successor Xerxes. A few months of battling determined the fate of the Western world. The Orientals were hurled back; the glorious memories of Marathon, Salamis, and Platæa stimulated the patriotism and enthusiasm of all children of the Greek race. The Greeks, for the first time, occupied the centre of the historical stage; for the brief interval of about half a century the different Grecian principalities lived together in relative harmony. One city was recognized as the metropolis of the loosely bound empire; one city became the home of culture and the Mecca towards which all eyes turned; that city, of course, was Athens. For a brief time all roads led to Athens, as, at a later date, they all led to Rome. The waterways which alone bound the widely scattered parts of Hellas into a united whole led out from Athens and back to Athens, as the spokes of a wheel to its hub. Athens was the commercial centre, and, largely for that reason, it became the centre of culture and intellectual influence also. The wise men from the colonies visited the metropolis, and the wise Athenians went out to the colonies. Whoever aspired to become a leader in politics, in art, in literature, or in philosophy, made his way to the capital, and so, with almost bewildering suddenness, there blossomed the civilization of the age of Pericles; the civilization which produced Æschylus, Sophocles, Euripides, Herodotus, and Thucydides; the civilization which made possible the building of the Parthenon.

ANAXAGORAS

Sometime during the early part of this golden age there came to Athens a middle-aged man from Clazomenæ, who, from our present stand-point, was a more interesting personality than perhaps any other in the great galaxy of remarkable men assembled there. The name of this new-comer was Anaxagoras. It was said in after-time, we know not with what degree of truth, that he had been a pupil of Anaximenes. If so, he was a pupil who departed far from the teachings of his master. What we know for certain is that Anaxagoras was a truly original thinker, and that he became a close friend—in a sense the teacher—of Pericles and of Euripides. Just how long he remained at Athens is not certain; but the time came when he had made himself in some way objectionable to the Athenian populace through his teachings. Filled with the spirit of the investigator, he could not accept the current conceptions as to the gods. He was a sceptic, an innovator. Such men are never welcome; they are the chief factors in the progress of thought, but they must look always to posterity for recognition of their worth; from their contemporaries they receive, not thanks, but persecution. Sometimes this persecution takes one form, sometimes another; to the credit of the Greeks be it said, that with them it usually led to nothing more severe than banishment. In the case of Anaxagoras, it is alleged that the sentence pronounced was death; but that, thanks to the influence of Pericles, this sentence was commuted to banishment. In any event, the aged philosopher was sent away from the city of his adoption. He retired to Lampsacus. "It is not I that have lost the Athenians," he said; "it is the Athenians that have lost me."

The exact position which Anaxagoras had among his contemporaries, and his exact place in the development of philosophy, have always been somewhat in dispute. It is not known, of a certainty, that he even held an open school at Athens. Ritter thinks it doubtful that he did. It was his fate to be misunderstood, or underestimated, by Aristotle; that in itself would have sufficed greatly to dim his fame—might, indeed, have led to his almost entire neglect had he not been a truly remarkable thinker. With most of the questions that have exercised the commentators we have but scant concern. Following Aristotle, most historians of philosophy have been metaphysicians; they have concerned themselves far less with what the ancient thinkers really knew than with what they thought. A chance using of a verbal quibble, an esoteric phrase, the expression of a vague mysticism—these would suffice to call forth reams of exposition. It has been the favorite pastime of historians to weave their own anachronistic theories upon the scanty woof of the half-remembered thoughts of the ancient philosophers. To make such cloth of the imagination as this is an alluring pastime, but one that must not divert us here. Our point of view reverses that of the philosophers. We are chiefly concerned, not with some vague saying of Anaxagoras, but with what he really knew regarding the phenomena of nature; with what he observed, and with the comprehensible deductions that he derived from his observations. In attempting to answer these inquiries, we are obliged, in part, to take our evidence at second-hand; but, fortunately, some fragments of writings of Anaxagoras have come down to us. We are told that he wrote only a single book. It was said even (by Diogenes) that he was the first man that ever wrote a work in prose. The latter statement would not bear too close an examination, yet it is true that no extensive prose compositions of an earlier day than this have been preserved, though numerous others are known by their fragments. Herodotus, "the father of prose," was a slightly younger contemporary of the Clazomenæan philosopher; not unlikely the two men may have met at Athens.

Notwithstanding the loss of the greater part of the writings of Anaxagoras, however, a tolerably precise account of his scientific doctrines is accessible. Diogenes Laertius expresses some of them in very clear and precise terms. We have already pointed out the uncertainty that attaches to such evidence as this, but it is as valid for Anaxagoras as for another. If we reject such evidence, we shall often have almost nothing left; in accepting it we may at least feel certain that we are viewing the thinker as his contemporaries and immediate successors viewed him. Following Diogenes, then, we shall find some remarkable scientific opinions ascribed to Anaxagoras. "He asserted," we are told, "that the sun was a mass of burning iron, greater than Peloponnesus, and that the moon contained houses and also hills and ravines." In corroboration of this, Plato represents him as having conjectured the right explanation of the moon's light, and of the solar and lunar eclipses. He had other astronomical theories that were more fanciful; thus "he said that the stars originally moved about in irregular confusion, so that at first the pole-star, which is continually visible, always appeared in the zenith, but that afterwards it acquired a certain declination, and that the Milky Way was a reflection of the light of the sun when the stars did not appear. The comets he considered to be a concourse of planets emitting rays, and the shooting-stars he thought were sparks, as it were, leaping from the firmament."

Much of this is far enough from the truth, as we now know it, yet all of it shows an earnest endeavor to explain the observed phenomena of the heavens on rational principles. To have predicated the sun as a great molten mass of iron was indeed a wonderful anticipation of the results of the modern spectroscope. Nor can it be said that this hypothesis of Anaxagoras was a purely visionary guess. It was in all probability a scientific deduction from the observed character of meteoric stones. Reference has already been made to the alleged prediction of the fall of the famous meteor at Ægespotomi by Anaxagoras. The assertion that he actually predicted this fall in any proper sense of the word would be obviously absurd. Yet the fact that his name is associated with it suggests that he had studied similar meteorites, or else that he studied this particular one, since it is not quite clear whether it was before or after this fall that he made the famous assertion that space is full of falling stones. We should stretch the probabilities were we to assert that Anaxagoras knew that shooting-stars and meteors were the same, yet there is an interesting suggestiveness in his likening the shooting-stars to sparks leaping from the firmament, taken in connection with his observation on meteorites. Be this as it may, the fact that something which falls from heaven as a blazing light turns out to be an iron-like mass may very well have suggested to the most rational of thinkers that the great blazing light called the sun has the same composition. This idea grasped, it was a not unnatural extension to conceive the other heavenly bodies as having the same composition.

This led to a truly startling thought. Since the heavenly bodies are of the same composition as the earth, and since they are observed to be whirling about the earth in space, may we not suppose that they were once a part of the earth itself, and that they have been thrown off by the force of a whirling motion? Such was the conclusion which Anaxagoras reached; such his explanation of the origin of the heavenly bodies. It was a marvellous guess. Deduct from it all that recent science has shown to be untrue; bear in mind that the stars are suns, compared with which the earth is a mere speck of dust; recall that the sun is parent, not daughter, of the earth, and despite all these deductions, the cosmogonic guess of Anaxagoras remains, as it seems to us, one of the most marvellous feats of human intelligence. It was the first explanation of the cosmic bodies that could be called, in any sense, an anticipation of what the science of our own day accepts as a true explanation of cosmic origins. Moreover, let us urge again that this was no mere accidental flight of the imagination; it was a scientific induction based on the only data available; perhaps it is not too much to say that it was the only scientific induction which these data would fairly sustain. Of course it is not for a moment to be inferred that Anaxagoras understood, in the modern sense, the character of that whirling force which we call centrifugal. About two thousand years were yet to elapse before that force was explained as elementary inertia; and even that explanation, let us not forget, merely sufficed to push back the barriers of mystery by one other stage; for even in our day inertia is a statement of fact rather than an explanation.

But however little Anaxagoras could explain the centrifugal force on mechanical principles, the practical powers of that force were sufficiently open to his observation. The mere experiment of throwing a stone from a sling would, to an observing mind, be full of suggestiveness. It would be obvious that by whirling the sling about, the stone which it held would be sustained in its circling path about the hand in seeming defiance of the earth's pull, and after the stone had left the sling, it could fly away from the earth to a distance which the most casual observation would prove to be proportionate to the speed of its flight. Extremely rapid motion, then, might project bodies from the earth's surface off into space; a sufficiently rapid whirl would keep them there. Anaxagoras conceived that this was precisely what had occurred. His imagination even carried him a step farther—to a conception of a slackening of speed, through which the heavenly bodies would lose their centrifugal force, and, responding to the perpetual pull of gravitation, would fall back to the earth, just as the great stone at Ægespotomi had been observed to do.

Here we would seem to have a clear conception of the idea of universal gravitation, and Anaxagoras stands before us as the anticipator of Newton. Were it not for one scientific maxim, we might exalt the old Greek above the greatest of modern natural philosophers; but that maxim bids us pause. It is phrased thus, "He discovers who proves." Anaxagoras could not prove; his argument was at best suggestive, not demonstrative. He did not even know the laws which govern falling bodies; much less could he apply such laws, even had he known them, to sidereal bodies at whose size and distance he could only guess in the vaguest terms. Still his cosmogonic speculation remains as perhaps the most remarkable one of antiquity. How widely his speculation found currency among his immediate successors is instanced in a passage from Plato, where Socrates is represented as scornfully answering a calumniator in these terms: "He asserts that I say the sun is a stone and the moon an earth. Do you think of accusing Anaxagoras, Miletas, and have you so low an opinion of these men, and think them so unskilled in laws, as not to know that the books of Anaxagoras the Clazomenæan are full of these doctrines. And forsooth the young men are learning these matters from me which sometimes they can buy from the orchestra for a drachma, at the most, and laugh at Socrates if he pretends they are his—particularly seeing they are so strange."

The element of error contained in these cosmogonic speculations of Anaxagoras has led critics to do them something less than justice. But there is one other astronomical speculation for which the Clazomenæan philosopher has received full credit. It is generally admitted that it was he who first found out the explanation of the phases of the moon; a knowledge that that body shines only by reflected light, and that its visible forms, waxing and waning month by month from crescent to disk and from disk to crescent, merely represent our shifting view of its sun-illumined face. It is difficult to put ourselves in the place of the ancient observer and realize how little the appearances suggest the actual fact. That a body of the same structure as the earth should shine with the radiance of the moon merely because sunlight is reflected from it, is in itself a supposition seemingly contradicted by ordinary experience. It required the mind of a philosopher, sustained, perhaps, by some experimental observations, to conceive the idea that what seems so obviously bright may be in reality dark. The germ of the conception of what the philosopher speaks of as the noumena, or actualities, back of phenomena or appearances, had perhaps this crude beginning. Anaxagoras could surely point to the moon in support of his seeming paradox that snow, being really composed of water, which is dark, is in reality black and not white—a contention to which we shall refer more at length in a moment.

But there is yet another striking thought connected with this new explanation of the phases of the moon. The explanation implies not merely the reflection of light by a dark body, but by a dark body of a particular form. Granted that reflections are in question, no body but a spherical one could give an appearance which the moon presents. The moon, then, is not merely a mass of earth, it is a spherical mass of earth. Here there were no flaws in the reasoning of Anaxagoras. By scientific induction he passed from observation to explanation. A new and most important element was added to the science of astronomy.

Looking back from the latter-day stand-point, it would seem as if the mind of the philosopher must have taken one other step: the mind that had conceived sun, moon, stars, and earth to be of one substance might naturally, we should think, have reached out to the further induction that, since the moon is a sphere, the other cosmic bodies, including the earth, must be spheres also. But generalizer as he was, Anaxagoras was too rigidly scientific a thinker to make this assumption. The data at his command did not, as he analyzed them, seem to point to this conclusion. We have seen that Pythagoras probably, and Parmenides surely, out there in Italy had conceived the idea of the earth's rotundity, but the Pythagorean doctrines were not rapidly taken up in the mother-country, and Parmenides, it must be recalled, was a strict contemporary of Anaxagoras himself. It is no reproach, therefore, to the Clazomenæan philosopher that he should have held to the old idea that the earth is flat, or at most a convex disk—the latter being the Babylonian conception which probably dominated that Milesian school to which Anaxagoras harked back.

Anaxagoras may never have seen an eclipse of the moon, and even if he had he might have reflected that, from certain directions, a disk may throw precisely the same shadow as a sphere. Moreover, in reference to the shadow cast by the earth, there was, so Anaxagoras believed, an observation open to him nightly which, we may well suppose, was not without influence in suggesting to his mind the probable shape of the earth. The Milky Way, which doubtless had puzzled astronomers from the beginnings of history and which was to continue to puzzle them for many centuries after the day of Anaxagoras, was explained by the Clazomenæan philosopher on a theory obviously suggested by the theory of the moon's phases. Since the earth-like moon shines by reflected light at night, and since the stars seem obviously brighter on dark nights, Anaxagoras was but following up a perfectly logical induction when he propounded the theory that the stars in the Milky Way seem more numerous and brighter than those of any other part of the heavens, merely because the Milky Way marks the shadow of the earth. Of course the inference was wrong, so far as the shadow of the earth is concerned; yet it contained a part truth, the force of which was never fully recognized until the time of Galileo. This consists in the assertion that the brightness of the Milky Way is merely due to the glow of many stars. The shadow-theory of Anaxagoras would naturally cease to have validity so soon as the sphericity of the earth was proved, and with it, seemingly, fell for the time the companion theory that the Milky Way is made up of a multitude of stars.

It has been said by a modern critic[1] that the shadow-theory was childish in that it failed to note that the Milky Way does not follow the course of the ecliptic. But this criticism only holds good so long as we reflect on the true character of the earth as a symmetrical body poised in space. It is quite possible to conceive a body occupying the position of the earth with reference to the sun which would cast a shadow having such a tenuous form as the Milky Way presents. Such a body obviously would not be a globe, but a long-drawn-out, attenuated figure. There is, to be sure, no direct evidence preserved to show that Anaxagoras conceived the world to present such a figure as this, but what we know of that philosopher's close-reasoning, logical mind gives some warrant to the assumption—gratuitous though in a sense it be—that the author of the theory of the moon's phases had not failed to ask himself what must be the form of that terrestrial body which could cast the tenuous shadow of the Milky Way. Moreover, we must recall that the habitable earth, as known to the Greeks of that day, was a relatively narrow band of territory, stretching far to the east and to the west.

Anaxagoras as Meteorologist

The man who had studied the meteorite of Ægospotami, and been put by it on the track of such remarkable inductions, was, naturally, not oblivious to the other phenomena of the atmosphere. Indeed, such a mind as that of Anaxagoras was sure to investigate all manner of natural phenomena, and almost equally sure to throw new light on any subject that it investigated. Hence it is not surprising to find Anaxagoras credited with explaining the winds as due to the rarefactions of the atmosphere produced by the sun. This explanation gives Anaxagoras full right to be called "the father of meteorology," a title which, it may be, no one has thought of applying to him, chiefly because the science of meteorology did not make its real beginnings until some twenty-four hundred years after the death of its first great votary. Not content with explaining the winds, this prototype of Franklin turned his attention even to the upper atmosphere. "Thunder," he is reputed to have said, "was produced by the collision of the clouds, and lightning by the rubbing together of the clouds." We dare not go so far as to suggest that this implies an association in the mind of Anaxagoras between the friction of the clouds and the observed electrical effects generated by the friction of such a substance as amber. To make such a suggestion doubtless would be to fall victim to the old familiar propensity to read into Homer things that Homer never knew. Yet the significant fact remains that Anaxagoras ascribed to thunder and to lightning their true position as strictly natural phenomena. For him it was no god that menaced humanity with thundering voice and the flash of his divine fires from the clouds. Little wonder that the thinker whose science carried him to such scepticism as this should have felt the wrath of the superstitious Athenians.

Biological Speculations

Passing from the phenomena of the air to those of the earth itself, we learn that Anaxagoras explained an earthquake as being produced by the returning of air into the earth. We cannot be sure as to the exact meaning here, though the idea that gases are imprisoned in the substance of the earth seems not far afield. But a far more remarkable insight than this would imply was shown by Anaxagoras when he asserted that a certain amount of air is contained in water, and that fishes breathe this air. The passage of Aristotle in which this opinion is ascribed to Anaxagoras is of sufficient interest to be quoted at length:

"Democritus, of Abdera," says Aristotle, "and some others, that have spoken concerning respiration, have determined nothing concerning other animals, but seem to have supposed that all animals respire. But

Anaxagoras and Diogenes (Apolloniates), who say that all animals respire, have also endeavored to explain how fishes, and all those animals that have a hard, rough shell, such as oysters, mussels, etc., respire. And Anaxagoras, indeed, says that fishes, when they emit water through their gills, attract air from the mouth to the vacuum in the viscera from the water which surrounds the mouth; as if air was inherent in the water."[2]

It should be recalled that of the three philosophers thus mentioned as contending that all animals respire, Anaxagoras was the elder; he, therefore, was presumably the originator of the idea. It will be observed, too, that Anaxagoras alone is held responsible for the idea that fishes respire air through their gills, "attracting" it from the water. This certainly was one of the shrewdest physiological guesses of any age, if it be regarded as a mere guess. With greater justice we might refer to it as a profound deduction from the principle of the uniformity of nature.

In making such a deduction, Anaxagoras was far in advance of his time as illustrated by the fact that Aristotle makes the citation we have just quoted merely to add that "such things are impossible," and to refute these "impossible" ideas by means of metaphysical reasonings that seemed demonstrative not merely to himself, but to many generations of his followers.

We are told that Anaxagoras alleged that all animals were originally generated out of moisture, heat, and earth particles. Just what opinion he held concerning man's development we are not informed. Yet there is one of his phrases which suggests—without, perhaps, quite proving—that he was an evolutionist. This phrase asserts, with insight that is fairly startling, that man is the most intelligent of animals because he has hands. The man who could make that assertion must, it would seem, have had in mind the idea of the development of intelligence through the use of hands—an idea the full force of which was not evident to subsequent generations of thinkers until the time of Darwin.

Physical Speculations

Anaxagoras is cited by Aristotle as believing that "plants are animals and feel pleasure and pain, inferring this because they shed their leaves and let them grow again." The idea is fanciful, yet it suggests again a truly philosophical conception of the unity of nature. The man who could conceive that idea was but little hampered by traditional conceptions. He was exercising a rare combination of the rigidly scientific spirit with the poetical imagination. He who possesses these gifts is sure not to stop in his questionings of nature until he has found some thinkable explanation of the character of matter itself. Anaxagoras found such an explanation, and, as good luck would have it, that explanation has been preserved. Let us examine his reasoning in some detail. We have already referred to the claim alleged to have been made by Anaxagoras that snow is not really white, but black. The philosopher explained his paradox, we are told, by asserting that snow is really water, and that water is dark, when viewed under proper conditions—as at the bottom of a well. That idea contains the germ of the Clazomenæan philosopher's conception of the nature of matter. Indeed, it is not unlikely that this theory of matter grew out of his observation of the changing forms of water. He seems clearly to have grasped the idea that snow on the one hand, and vapor on the other, are of the same intimate substance as the water from which they are derived and into which they may be again transformed. The fact that steam and snow can be changed back into water, and by simple manipulation cannot be changed into any other substance, finds, as we now believe, its true explanation in the fact that the molecular structure, as we phrase it—that is to say, the ultimate particle of which water is composed, is not changed, and this is precisely the explanation which Anaxagoras gave of the same phenomena. For him the unit particle of water constituted an elementary body, uncreated, unchangeable, indestructible. This particle, in association with like particles, constitutes the substance which we call water. The same particle in association with particles unlike itself, might produce totally different substances — as, for example, when water is taken up by the roots of a plant and becomes, seemingly, a part of the substance of the plant. But whatever the changed association, so Anaxagoras reasoned, the ultimate particle of water remains a particle of water still. And what was true of water was true also, so he conceived, of every other substance. Gold, silver, iron, earth, and the various vegetables and animal tissues—in short, each and every one of all the different substances with which experience makes us familiar, is made up of unit particles which maintain their integrity in whatever combination they may be associated. This implies, obviously, a multitude of primordial particles, each one having an individuality of its own; each one, like the particle of water already cited, uncreated, unchangeable, and indestructible.

Fortunately, we have the philosopher's own words to guide us as to his speculations here. The fragments of his writings that have come down to us (chiefly through the quotations of Simplicius) deal almost exclusively with these ultimate conceptions of his imagination. In ascribing to him, then, this conception of diverse, uncreated, primordial elements, which can never be changed, but can only be mixed together to form substances of the material world, we are not reading back post-Daltonian knowledge into the system of Anaxagoras. Here are his words: "The Greeks do not rightly use the terms 'coming into being' and 'perishing.' For nothing comes into being, nor, yet, does anything perish; but there is mixture and separation of things that are. So they would do right in calling 'coming into being' 'mixture' and 'perishing' 'separation.' For how could hair come from what is not hair? Or flesh from what is not flesh?"

Elsewhere he tells us that (at one stage of the world's development) "the dense, the moist, the cold, the dark, collected there where now is earth; the rare, the warm, the dry, the bright, departed towards the further part of the æther. The earth is condensed out of these things that are separated, for water is separated from the clouds, and earth from the water; and from the earth stones are condensed by the cold, and these are separated farther from the water." Here again the influence of heat and cold in determining physical qualities is kept pre-eminently in mind. The dense, the moist, the cold, the dark are contrasted with the rare, the warm, the dry, and bright; and the formation of stones is spoken of as a specific condensation due to the influence of cold. Here, then, we have nearly all the elements of the Daltonian theory of atoms on the one hand, and the nebular hypothesis of Laplace on the other. But this is not quite all. In addition to such diverse elementary particles as those of gold, water, and the rest, Anaxagoras conceived a species of particles differing from all the others, not merely as they differ from one another, but constituting a class by themselves; particles infinitely smaller than the others; particles that are described as infinite, self-powerful, mixed with nothing, but existing alone. That is to say (interpreting the theory in the only way that seems plausible), these most minute particles do not mix with the other primordial particles to form material substances in the same way in which these mixed with one another. But, on the other hand, these "infinite, self-powerful, and unmixed" particles commingle everywhere and in every substance whatever with the mixed particles that go to make up the substances.

There is a distinction here, it will be observed, which at once suggests the modern distinction between physical processes and chemical processes, or, putting it otherwise, between molecular processes and atomic processes; but the reader must be guarded against supposing that Anaxagoras had any such thought as this in mind. His ultimate mixable particles can be compared only with the Daltonian atom, not with the molecule of the modern physicist, and his "infinite, self-powerful, and unmixable" particles are not comparable with anything but the ether of the modern physicist, with which hypothetical substance they have many points of resemblance. But the "infinite, self-powerful, and unmixed" particles constituting thus an ether-like plenum which permeates all material structures, have also, in the mind of Anaxagoras, a function which carries them perhaps a stage beyond the province of the modern ether. For these "infinite, self-powerful, and unmixed" particles are imbued with, and, indeed, themselves constitute, what Anaxagoras terms *nous*, a word which the modern translator has usually paraphrased as "mind." Neither that word nor any other available one probably conveys an accurate idea of what Anaxagoras meant to imply by the word *nous*. For him the word meant not merely "mind" in the sense of receptive and comprehending intelligence, but directive and creative intelligence as well. Again let Anaxagoras speak for himself: "Other things include a portion of everything, but *nous* is infinite, and self-powerful, and mixed with nothing, but it exists alone, itself by itself. For if it were not by itself, but were mixed with anything else, it would include parts of all things, if it were mixed with anything; for a portion of everything exists in everything, as has been said by me before, and things mingled with it would prevent it from having power over anything in the same way that it does now that it is alone by itself. For it is the most rarefied of all things and the purest, and it has all knowledge in regard to everything and the greatest power; over all that has life, both greater and less, *nous* rules. And *nous* ruled the rotation of the whole, so that it set it in rotation in the beginning. First it began the rotation from a small beginning, then more and more was included in the motion, and yet more will be included. Both the mixed and the separated and distinct, all things *nous* recognized. And whatever things were to be, and whatever things were, as many as are now, and whatever things shall be, all these *nous* arranged in order; and it arranged that rotation, according to which now rotate stars and sun and moon and air and æther, now that they are separated. Rotation itself caused the separation, and the dense is separated from the rare, the warm from the cold, the bright from the dark, the dry from the moist. And when *nous* began to set things in motion, there was separation from everything that was in motion, all this was made distinct. The rotation of the things that were moved and made distinct caused them to be yet more distinct."[3]

Nous, then, as Anaxagoras conceives it, is "the most rarefied of all things, and the purest, and it has knowledge in regard to everything and the greatest power; over all that has life, both greater and less, it rules." But these are postulants of omnipresence and omniscience. In other words, *nous* is nothing less than the omnipotent artificer of the material universe. It lacks nothing of the power of deity, save only that we are not assured that it created the primordial particles. The creation of these particles was a conception that for Anaxagoras, as for the modern Spencer, lay beyond the range of imagination. *Nous* is the artificer, working with "uncreated" particles. Back of *nous* and the particles lies, for an Anaxagoras as for a Spencer, the Unknowable. But *nous* itself is the equivalent of that universal energy of motion which science recognizes as operating between the particles of matter, and which the theologist personifies as Deity. It is Pantheistic deity as Anaxagoras conceives it; his may be called the first scientific conception of a non-anthropomorphic god. In elaborating this conception Anaxagoras proved himself one of the most remarkable scientific dreamers of antiquity. To have substituted for the Greek Pantheon of anthropomorphic deities the conception of a non-anthropomorphic immaterial and ethereal entity, of all things in the world "the most rarefied and the purest," is to have performed a feat which, considering the age and the environment in which it was accomplished, staggers the imagination. As a strictly scientific accomplishment the great thinker's conception of primordial elements contained a germ of the truth which was to lie dormant for 2200 years, but which then, as modified and vitalized by the genius of Dalton, was to dominate the new chemical science of the nineteenth century. If there are intimations that the primordial element of Anaxagoras and of Dalton may turn out in the near future to be itself a compound, there will still remain the yet finer particles of the *nous* of Anaxagoras to baffle the most subtle analysis of which to-day's science gives us any pre-vision. All in all, then, the work of Anaxagoras must stand as that of perhaps the most far-seeing scientific imagination of pre-Socratic antiquity.

LEUCIPPUS AND DEMOCRITUS

But we must not leave this alluring field of speculation as to the nature of matter without referring to another scientific guess, which soon followed that of Anaxagoras and was destined to gain even wider fame, and which in modern times has been somewhat unjustly held to eclipse the glory of the other achievement. We mean, of course, the atomic theory of Leucippus and Democritus. This theory reduced all matter to primordial elements, called atoms ἄτομα because they are by hypothesis incapable of further division. These atoms, making up the entire material universe, are in this theory conceived as qualitatively identical, differing from one another only in size and perhaps in shape. The union of different-sized atoms in endless combinations produces the diverse substances with which our senses make us familiar.

Before we pass to a consideration of this alluring theory, and particularly to a comparison of it with the theory of Anaxagoras, we must catch a glimpse of the personality of the men to whom the theory owes its origin. One of these, Leucippus, presents so uncertain a figure as to be almost mythical. Indeed, it was long questioned whether such a man had actually lived, or whether he were not really an invention of his alleged disciple, Democritus. Latter-day scholarship, however, accepts him as a real personage, though knowing scarcely more of him than that he was the author of the famous theory with which his name was associated. It is suggested that he was a wanderer, like most philosophers of his time, and that later in life he came to Abdera, in Thrace, and through this circumstance became the teacher of Democritus. This fable answers as well as another. What we really know is that Democritus himself, through whose writings and teachings the atomic theory gained vogue, was born in Abdera, about the year 460 B.C.—that is to say, just about the time when his great precursor, Anaxagoras, was migrating to Athens. Democritus, like most others of the early Greek thinkers, lives in tradition as a picturesque figure. It is vaguely reported that he travelled for a time, perhaps in the East and in Egypt, and that then he settled down to spend the remainder of his life in Abdera. Whether or not he visited Athens in the course of his wanderings we do not know. At Abdera he was revered as a sage, but his influence upon the practical civilization of the time was not marked. He was pre-eminently a dreamer and a writer. Like his confrères of the epoch, he entered all fields of thought. He wrote voluminously, but, unfortunately, his writings have, for the most part, perished. The fables and traditions of a later day asserted that Democritus had voluntarily put out his own eyes that he might turn his thoughts inward with more concentration. Doubtless this is fiction, yet, as usual with such fictions, it contains a germ of truth; for we may well suppose that the promulgator of the atomic theory was a man whose mind was attracted by the subtleties of thought rather than by the tangibilities of observation. Yet the term "laughing philosopher," which seems to have been universally applied to Democritus, suggests a mind not altogether withdrawn from the world of practicalities.

So much for Democritus the man. Let us return now to his theory of atoms. This theory, it must be confessed, made no very great impression upon his contemporaries. It found an expositor, a little later, in the philosopher Epicurus, and later still the poet Lucretius gave it popular expression. But it seemed scarcely more than the dream of a philosopher or the vagary of a poet until the day when modern science began to penetrate the mysteries of matter. When, finally, the researches of Dalton and his followers had placed the atomic theory on a surer footing as the foundation of modern chemistry, the ideas of the old laughing philosopher of Abdera, which all along had been half derisively remembered, were recalled with a new interest. Now it appeared that these ideas had curiously foreshadowed nineteenth-century knowledge. It appeared that away back in the fifth century B.C. a man had dreamed out a conception of the ultimate nature of matter which had waited all these centuries for corroboration. And now the historians of philosophy became more than anxious to do justice to the memory of Democritus.

It is possible that this effort at poetical restitution has carried the enthusiast too far. There is, indeed, a curious suggestiveness in the theory of Democritus; there is philosophical allurement in his reduction of all matter to a single element; it contains, it may be, not merely a germ of the science of the nineteenth-century chemistry, but perhaps the germs also of the yet undeveloped chemistry of the twentieth century. Yet we dare suggest that in their enthusiasm for the atomic theory of Democritus the historians of our generation have done something less than justice to that philosopher's precursor, Anaxagoras. And one suspects that the mere accident of a name has been instrumental in producing this result. Democritus called his primordial element an atom; Anaxagoras, too, conceived a primordial element, but he called it merely a seed or thing; he failed to christen it distinctively. Modern science adopted the word atom and gave it universal vogue. It owed a debt of gratitude to Democritus for supplying it the word, but it somewhat overpaid the debt in too closely linking the new meaning of the word with its old original one. For, let it be clearly understood, the Daltonian atom is not precisely comparable with the atom of Democritus. The atom, as Democritus conceived it, was monistic; all atoms, according to this hypothesis, are of the same substance; one atom differs from another merely in size and shape, but not at all in quality. But the Daltonian hypothesis conceived, and nearly all the experimental efforts of the nineteenth century seemed to prove, that there are numerous classes of atoms, each differing in its very essence from the others.

As the case stands to-day the chemist deals with seventy-odd substances, which he calls elements. Each one of these substances is, as he conceives it, made up of elementary atoms having a unique personality, each differing in quality from all the others. As far as experiment has thus far safely carried us, the atom of gold is a primordial element which remains an atom of gold and nothing else, no matter with what other atoms it is associated. So, too, of the atom of silver, or zinc, or sodium — in short, of each and every one of the seventy-odd elements. There are, indeed, as we shall see, experiments that suggest the dissolution of the atom—that suggest, in short, that the Daltonian atom is misnamed, being a structure that may, under certain conditions, be broken asunder. But these experiments have, as yet, the warrant rather of philosophy than of pure science, and to-day we demand that the philosophy of science shall be the handmaid of experiment.

When experiment shall have demonstrated that the Daltonian atom is a compound, and that in truth there is but a single true atom, which, combining with its fellows perhaps in varying numbers and in different special relations, produces the Daltonian atoms, then the philosophical theory of monism will have the experimental warrant which to-day it lacks; then we shall be a step nearer to the atom of Democritus in one direction, a step farther away in the other. We shall be nearer, in that the conception of Democritus was, in a sense, monistic; farther away, in that all the atoms of Democritus, large and small alike, were considered as permanently fixed in size. Democritus postulated all his atoms as of the same substance, differing not at all in quality; yet he was obliged to conceive that the varying size of the atoms gave to them varying functions which amounted to qualitative differences. He might claim for his largest atom the same quality of substance as for his smallest, but so long as he conceived that the large atoms, when adjusted together to form a tangible substance, formed a substance different in quality from the substance which the small atoms would make up when similarly grouped, this concession amounts to the predication of difference of quality between the atoms themselves. The entire question reduces itself virtually to a quibble over the word quality. So long as one atom conceived to be primordial and indivisible is conceded to be of such a nature as necessarily to produce a different impression on our senses, when grouped with its fellows, from the impression produced by other atoms when similarly grouped, such primordial atoms do differ among themselves in precisely the same way for all practical purposes as do the primordial elements of Anaxagoras.

The monistic conception towards which twentieth-century chemistry seems to be carrying us may perhaps show that all the so-called atoms are compounded of a single element. All the true atoms making up that element may then properly be said to have the same quality, but none the less will it remain true that the combinations of that element that go to make up the different Daltonian atoms differ from one another in quality in precisely the same sense in which such tangible substances as gold, and oxygen, and mercury, and diamonds differ from one another. In the last analysis of the monistic philosophy, there is but one substance and one quality in the universe. In the widest view of that philosophy, gold and oxygen and mercury and diamonds are one substance, and, if you please, one quality. But such refinements of analysis as this are for the transcendental philosopher, and not for the scientist. Whatever the allurement of such reasoning, we must for the purpose of science let words have a specific meaning, nor must we let a mere word-jugglery blind us to the evidence of facts. That was the rock on which Greek science foundered; it is the rock which the modern helmsman sometimes finds it difficult to avoid. And if we mistake not, this case of the atom of Democritus is precisely a case in point. Because Democritus said that his atoms did not differ in quality, the modern philosopher has seen in his theory the essentials of monism; has discovered in it not merely a forecast of the chemistry of the nineteenth century, but a forecast of the hypothetical chemistry of the future. And, on the other hand, because Anaxagoras predicted a different quality for his primordial elements, the philosopher of our day has discredited the primordial element of Anaxagoras.

Yet if our analysis does not lead us astray, the theory of Democritus was not truly monistic; his indestructible atoms, differing from one another in size and shape, utterly incapable of being changed from the form which they had maintained from the beginning, were in reality as truly and primordially different as are the primordial elements of Anaxagoras. In other words, the atom of Democritus is nothing less than the primordial seed of Anaxagoras, a little more tangibly visualized and given a distinctive name. Anaxagoras explicitly conceived his elements as invisibly small, as infinite in number, and as made up of an indefinite number of kinds—-one for each distinctive substance in the world. But precisely the same postulates are made of the atom of Democritus. These also are invisibly small; these also are infinite in number; these also are made up of an indefinite number of kinds, corresponding with the observed difference of substances in the world. "Primitive seeds," or "atoms," were alike conceived to be primordial, unchangeable, and indestructible. Wherein then lies the difference? We answer, chiefly in a name; almost solely in the fact that Anaxagoras did not attempt to postulate the physical properties of the elements beyond stating that each has a distinctive personality, while Democritus did attempt to postulate these properties. He, too, admitted that each kind of element has its distinctive personality, and he attempted to visualize and describe the characteristics of the personality.

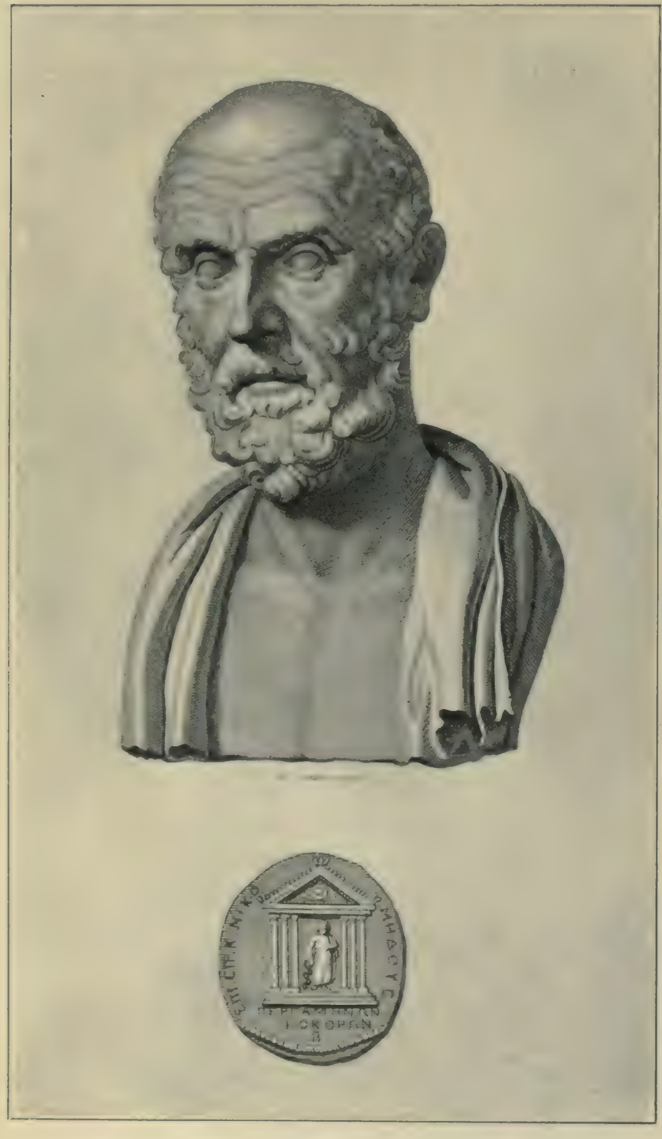
Thus while Anaxagoras tells us nothing of his elements except that they differ from one another, Democritus postulates a difference in size, imagines some elements as heavier and some as lighter, and conceives even that the elements may be provided with projecting hooks, with the aid of which they link themselves one with another. No one to-day takes these crude visualizings seriously as to their details. The sole element of truth which these dreamings contain, as distinguishing them from the dreamings of Anaxagoras, is in the conception that the various atoms differ in size and weight. Here, indeed, is a vague foreshadowing of that chemistry of form which began to come into prominence towards the close of the nineteenth century. To have forecast even dimly this newest phase of chemical knowledge, across the abyss of centuries, is indeed a feat to put Democritus in the front rank of thinkers. But this estimate should not blind us to the fact that the pre-vision of Democritus was but a slight elaboration of a theory which had its origin with another thinker. The association between Anaxagoras and Democritus cannot be directly traced, but it is an association which the historian of ideas should never for a moment forget. If we are not to be misled by mere word-jugglery, we shall recognize the founder of the atomic theory of matter in Anaxagoras; its expositors along slightly different lines in Leucippus and Democritus; its rediscoverer of the nineteenth century in Dalton. All in all, then, just as Anaxagoras preceded Democritus in time, so must he take precedence over him also as an inductive thinker, who carried the use of the scientific imagination to its farthest reach.

An analysis of the theories of the two men leads to somewhat the same conclusion that might be reached from a comparison of their lives. Anaxagoras was a sceptical, experimental scientist, gifted also with the prophetic imagination. He reasoned always from the particular to the general, after the manner of true induction, and he scarcely took a step beyond the confines of secure induction. True scientist that he was, he could content himself with postulating different qualities for his elements, without pretending to know how these qualities could be defined. His elements were by hypothesis invisible, hence he would not attempt to visualize them. Democritus, on the other hand, refused to recognize this barrier. Where he could not know, he still did not hesitate to guess. Just as he conceived his atom of a definite form with a definite structure, even so he conceived that the atmosphere about him was full of invisible spirits; he accepted the current superstitions of his time. Like the average Greeks of his day, he even believed in such omens as those furnished by inspecting the entrails of a fowl. These chance bits of biography are weather-vanes of the mind of Democritus. They tend to substantiate our conviction that Democritus must rank below Anaxagoras as a devotee of pure science. But, after all, such comparisons and estimates as this are utterly futile. The essential fact for us is that here, in the fifth century before our era, we find put forward the most penetrating guess as to the constitution of matter that the history of ancient thought has to present to us. In one direction, the avenue of progress is barred; there will be no farther step that way till we come down the centuries to the time of Dalton.

HIPPOCRATES AND GREEK MEDICINE

These studies of the constitution of matter have carried us to the limits of the field of scientific imagination in antiquity; let us now turn sharply and consider a department of science in which theory joins hands with practicality. Let us witness the beginnings of scientific therapeutics.

Medicine among the early Greeks, before the time of Hippocrates, was a crude mixture of religion, necromancy, and mysticism. Temples were erected to



HIPPOCRATES

the god of medicine, Æsculapius, and sick persons made their way, or were carried, to these temples, where they sought to gain the favor of the god by suitable offerings, and learn the way to regain their health through remedies or methods revealed to them in dreams by the god. When the patient had been thus cured, he placed a tablet in the temple describing his sickness, and telling by what method the god had cured him. He again made suitable offerings at the temple, which were sometimes in the form of gold or silver representations of the diseased organ—a gold or silver model of a heart, hand, foot, etc.

Nevertheless, despite this belief in the supernatural, many drugs and healing lotions were employed, and the Greek physicians possessed considerable skill in dressing wounds and bandaging. But they did not depend upon these surgical dressings alone, using with them certain appropriate prayers and incantations, recited over the injured member at the time of applying the dressings.

Even the very early Greeks had learned something of anatomy. The daily contact with wounds and broken bones must of necessity lead to a crude understanding of anatomy in general. The first Greek anatomist, however, who is recognized as such, is said to have been Alcmæon. He is said to have made extensive dissections of the lower animals, and to have described many hitherto unknown structures, such as the optic nerve and the Eustachian canal—the small tube leading into the throat from the ear. He is credited with many unique explanations of natural phenomena, such as, for example, the explanation that "hearing is produced by the hollow bone behind the ear; for all hollow things are sonorous." He was a rationalist, and he taught that the brain is the organ of mind. The sources of our information about his work, however, are unreliable.

Democedes, who lived in the sixth century B.C., is the first physician of whom we have any trustworthy history. We learn from Herodotus that he came from Croton to Ægina, where, in recognition of his skill, he was appointed medical officer of the city. From Ægina he was called to Athens at an increased salary, and later was in charge of medical affairs in several other Greek cities. He was finally called to Samos by the tyrant Polycrates, who reigned there from about 536 to 522 B.C. But on the death of Polycrates, who was murdered by the Persians, Democedes became a slave. His fame as a physician, however, had reached the ears of the Persian monarch, and shortly after his capture he was permitted to show his skill upon King Darius himself. The Persian monarch was suffering from a sprained ankle, which his Egyptian surgeons had been unable to cure. Democedes not only cured the injured member but used his influence in saving the lives of his Egyptian rivals, who had been condemned to death by the king.

At another time he showed his skill by curing the queen, who was suffering from a chronic abscess of long standing. This so pleased the monarch that he offered him as a reward anything he might desire, except his liberty. But the costly gifts of Darius did not satisfy him so long as he remained a slave; and determined to secure his freedom at any cost, he volunteered to lead some Persian spies into his native country, promising to use his influence in converting some of the leading men of his nation to the Persian cause. Laden with the wealth that had been heaped upon him by Darius, he set forth upon his mission, but upon reaching his native city of Croton he threw off his mask, renounced his Persian mission, and became once more a free Greek.

While the story of Democedes throws little light upon the medical practices of the time, it shows that paid city medical officers existed in Greece as early as the fifth and sixth centuries B.C. Even then there were different "schools" of medicine, whose disciples disagreed radically in their methods of treating diseases; and there were also specialists in certain diseases, quacks, and charlatans. Some physicians depended entirely upon external lotions for healing all disorders; others were "hydrotherapeutists" or "bath-physicians"; while there were a host of physicians who administered a great variety of herbs and drugs. There were also magicians who pretended to heal by sorcery, and great numbers of bone-setters, oculists, and dentists.

Many of the wealthy physicians had hospitals, or clinics, where patients were operated upon and treated. They were not hospitals in our modern understanding of the term, but were more like dispensaries, where patients were treated temporarily, but were not allowed to remain for any length of time. Certain communities established and supported these dispensaries for the care of the poor.

But anything approaching a rational system of medicine was not established, until Hippocrates of Cos, the "father of medicine," came upon the scene. In an age that produced Phidias, Lysias, Herodotus, Sophocles, and Pericles, it seems but natural that the medical art should find an exponent who would rise above superstitious dogmas and lay the foundation for a medical science. His rejection of the supernatural alone stamps the greatness of his genius. But, besides this, he introduced more detailed observation of diseases, and demonstrated the importance that attaches to prognosis.

Hippocrates was born at Cos, about 460 B.C., but spent most of his life at Larissa, in Thessaly. He was educated as a physician by his father, and travelled extensively as an itinerant practitioner for several years. His travels in different climates and among many different people undoubtedly tended to sharpen his keen sense of observation. He was a practical physician as well as a theorist, and, withal, a clear and concise writer. "Life is short," he says, "opportunity fleeting, judgment difficult, treatment easy, but treatment after thought is proper and profitable."

His knowledge of anatomy was necessarily very imperfect, and was gained largely from his predecessors, to whom he gave full credit. Dissections of the human body were forbidden him, and he was obliged to confine his experimental researches to operations on the lower animals. His knowledge of the structure and arrangement of the bones, however, was fairly accurate, but the anatomy of the softer tissues, as he conceived it, was a queer jumbling together of blood-vessels, muscles, and tendons. He does refer to "nerves," to be sure, but apparently the structures referred to are the tendons and ligaments, rather than the nerves themselves. He was better acquainted with the principal organs in the cavities of the body, and knew, for example, that the heart is divided into four cavities, two of which he supposed to contain blood, and the other two air.

His most revolutionary step was his divorcing of the supernatural from the natural, and establishing the fact that disease is due to natural causes and should be treated accordingly. The effect of such an attitude can hardly be over-estimated. The establishment of such a theory was naturally followed by a close observation as to the course of diseases and the effects of treatment. To facilitate this, he introduced the custom of writing down his observations as he made them—the "clinical history" of the case. Such clinical records are in use all over the world to-day, and their importance is so obvious that it is almost incomprehensible that they should have fallen into disuse shortly after the time of Hippocrates, and not brought into general use again until almost two thousand years later.

But scarcely less important than his recognition of disease as a natural phenomenon was the importance he attributed to prognosis. Prognosis, in the sense of prophecy, was common before the time of Hippocrates. But prognosis, as he practised it and as we understand it to-day, is prophecy based on careful observation of the course of diseases—something more than superstitious conjecture.

Although Hippocratic medicine rested on the belief in natural causes, nevertheless, dogma and theory held an important place. The *humoral* theory of disease was an all-important one, and so fully was this theory accepted that it influenced the science of medicine all through succeeding centuries. According to this celebrated theory there are four humors in the body—blood, phlegm, yellow bile, and black bile. When these humors are mixed in exact proportions they constitute health; but any deviations from these proportions produce disease. In treating diseases the aim of the physician was to discover which of these humors were out of proportion and to restore them to their natural equilibrium. It was in the methods employed in this restitution, rather than a disagreement about the humors themselves, that resulted in the various "schools" of medicine.

In many ways the surgery of Hippocrates showed a better understanding of the structure of the organs than of their functions. Some of the surgical procedures as described by him are followed, with slight modifications, to-day. Many of his methods were entirely lost sight of until modern times, and one, the treatment of dislocation of the outer end of the collar-bone, was not revived until some time in the eighteenth century.

Hippocrates, it seems, like modern physicians, sometimes suffered from the ingratitude of his patients. "The physician visits a patient suffering from fever or a wound, and prescribes for him," he says; "on the next day, if the patient feels worse the blame is laid upon the physician; if, on the other hand, he feels better, nature is extolled, and the physician reaps no praise."

The essence of this has been repeated in rhyme and prose by writers in every age and country, but the "father of medicine" cautions physicians against allowing it to influence their attitude towards their profession.

VIII

POST-SOCRATIC SCIENCE AT ATHENS—PLATO, ARISTOTLE, AND THEOPHRASTUS

DOUBTLESS it has been noticed that our earlier scientists were as far removed as possible from the limitations of specialism. In point of fact, in this early day, knowledge had not been classified as it came to be later on. The philosopher was, as his name implied, a lover of knowledge, and he did not find it beyond the reach of his capacity to apply himself to all departments of the field of human investigation. It is nothing strange to discover that Anaximander and the Pythagoreans and Anaxagoras have propounded theories regarding the structure of the cosmos, the origin and development of animals and man, and the nature of matter itself. Nowadays, so enormously involved has become the mass of mere facts regarding each of these departments of knowledge that no one man has the temerity to attempt to master them all. But it was different in those days of beginnings. Then the methods of observation were still crude, and it was quite the custom for a thinker of forceful personality to find an eager following among disciples who never thought of putting his theories to the test of experiment. The great lesson that true science in the last resort depends upon observation and measurement, upon compass and balance, had not yet been learned, though here and there a thinker like Anaxagoras had gained an inkling of it.

For the moment, indeed, there in Attica, which was now, thanks to that outburst of Periclean culture, the centre of the world's civilization, the trend of thought was to take quite another direction. The very year which saw the birth of Democritus at Abdera, and of Hippocrates, marked also the birth, at Athens, of another remarkable man, whose influence it would scarcely be possible to over-estimate. This man was Socrates. The main facts of his history are familiar to every one. It will be recalled that Socrates spent his entire life in Athens, mingling everywhere with the populace; haranguing, so the tradition goes, every one who would listen; inculcating moral lessons, and finally incurring the disapprobation of at least a voting majority of his fellow-citizens. He gathered about him a company of remarkable men with Plato at their head, but this could not save him from the disapprobation of the multitudes, at whose hands he suffered death, legally administered after a public trial. The facts at command as to certain customs of the Greeks at this period make it possible to raise a question as to whether the alleged "corruption of youth," with which Socrates was charged, may not have had a different implication from what posterity has preferred to ascribe to it. But this thought, almost shocking to the modern mind and seeming altogether sacrilegious to most students of Greek philosophy, need not here detain us; neither have we much concern in the present connection with any part of the teaching of the martyred philosopher. For the historian of metaphysics, Socrates marks an epoch, but for the historian of science he is a much less consequential figure.

Similarly regarding Plato, the aristocratic Athenian who sat at the feet of Socrates, and through whose writings the teachings of the master found widest currency. Some students of philosophy find in Plato "the greatest thinker and writer of all time."[1] The student of science must recognize in him a thinker whose point of view was essentially non-scientific; one who tended always to reason from the general to the particular rather than from the particular to the general. Plato's writings covered almost the entire field of thought, and his ideas were presented with such literary charm that successive generations of readers turned to them with unflagging interest, and gave them wide currency through copies that finally preserved them to our own time. Thus we are not obliged in his case, as we are in the case of every other Greek philosopher, to estimate his teachings largely from hearsay evidence. Plato himself speaks to us directly. It is true, the literary form which he always adopted, namely, the dialogue, does not give quite the same certainty as to when he is expressing his own opinions that a more direct narrative would have given; yet, in the main, there is little doubt as to the tenor of his own opinions—except, indeed, such doubt as always attaches to the philosophical reasoning of the abstract thinker.

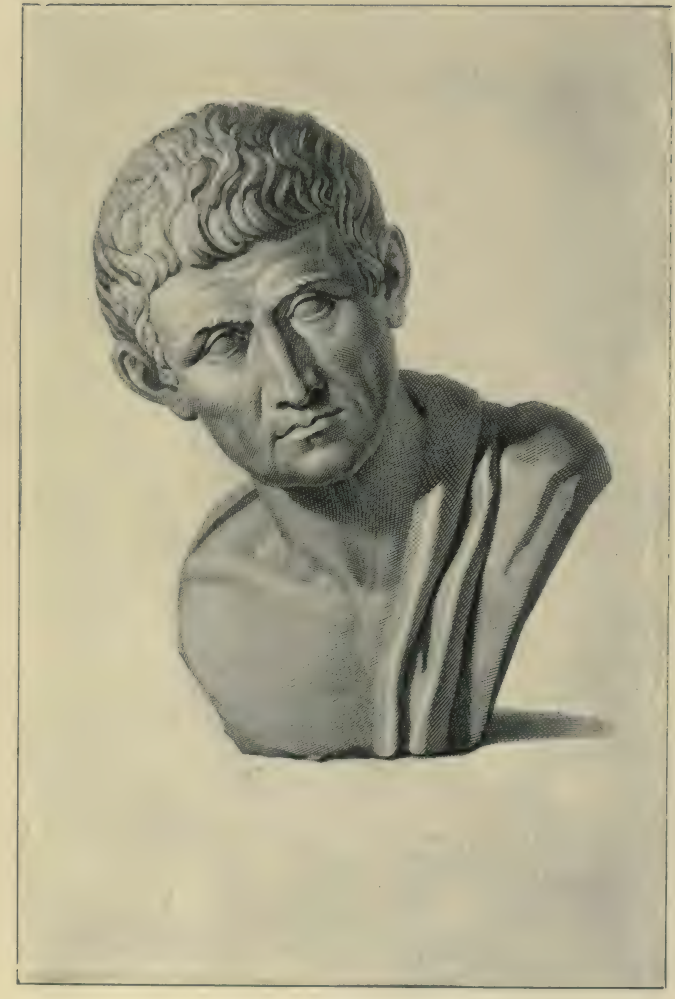
What is chiefly significant from our present standpoint is that the great ethical teacher had no significant message to give the world regarding the physical sciences. He apparently had no sharply defined opinions as to the mechanism of the universe; no clear conception as to the origin or development of organic beings; no tangible ideas as to the problems of physics; no favorite dreams as to the nature of matter. Virtually his back was turned on this entire field of thought. He was under the sway of those innate ideas which, as we have urged, were among the earliest inductions of science. But he never for a moment suspected such an origin for these ideas. He supposed his conceptions of being, his standards of ethics, to lie back of all experience; for him they were the most fundamental and most dependable of facts. He criticised Anaxagoras for having tended to deduce general laws from observation. As we moderns see it, such criticism is the highest possible praise. It is a criticism that marks the distinction between the scientist who is also a philosopher and the philosopher who has but a vague notion of physical science. Plato seemed, indeed, to realize the value of scientific investigation; he referred to the astronomical studies of the Egyptians and Chaldeans, and spoke hopefully of the results that might accrue were such studies to be taken up by that Greek mind which, as he justly conceived, had the power to vitalize and enrich all that it touched. But he told here of what he would have others do, not of what he himself thought of doing. His voice was prophetic, but it stimulated no worker of his own time.

Plato himself had travelled widely. It is a familiar legend that he lived for years in Egypt, endeavoring there to penetrate the mysteries of Egyptian science.

It is said even that the rudiments of geometry which he acquired there influenced all his later teachings. But be that as it may, the historian of science must recognize in the founder of the Academy a moral teacher and metaphysical dreamer and sociologist, but not, in the modern acceptance of the term, a scientist. Those wider phases of biological science which find their expression in metaphysics, in ethics, in political economy, lie without our present scope; and for the development of those subjects with which we are more directly concerned, Plato, like his master, has a negative significance.

ARISTOTLE (384–322 B.C.)

When we pass to that third great Athenian teacher, Aristotle, the case is far different. Here was a man whose name was to be received as almost a synonym for Greek science for more than a thousand years after his death. All through the Middle Ages his writings were to be accepted as virtually the last word regarding the problems of nature. We shall see that his followers actually preferred his mandate to the testimony of their own senses. We shall see, further, that modern science progressed somewhat in proportion as it overthrew the Aristotelian dogmas. But the traditions of seventeen or eighteen centuries are not easily set aside, and it is perhaps not too much to say that the name of Aristotle stands, even in our own time, as vaguely representative in the popular mind of all that was highest and best in the science of antiquity. Yet, perhaps, it would not be going too far to assert that something like a reversal of this judg-



ARISTOTLE

ment would be nearer the truth. Aristotle did, indeed, bring together a great mass of facts regarding animals in his work on natural history, which, being preserved, has been deemed to entitle its author to be called the "father of zoology." But there is no reason to suppose that any considerable portion of this work contained matter that was novel, or recorded observations that were original with Aristotle; and the classifications there outlined are at best but a vague foreshadowing of the elaboration of the science. Such as it is, however, the natural history stands to the credit of the Stagirite. He must be credited, too, with a clear enunciation of one most important scientific doctrine—namely, the doctrine of the spherical figure of the earth. We have already seen that this theory originated with the Pythagorean philosophers out in Italy. We have seen, too, that the doctrine had not made its way in Attica in the time of Anaxagoras. But in the intervening century it had gained wide currency, else so essentially conservative a thinker as Aristotle would scarcely have accepted it. He did accept it, however, and gave the doctrine clearest and most precise expression. Here are his words:[2]

"As to the figure of the earth it must necessarily be spherical. . . . If it were not so, the eclipses of the moon would not have such sections as they have. For in the configurations in the course of a month the deficient part takes all different shapes; it is straight, and concave, and convex; but in eclipses it always has the line of divisions convex; wherefore, since the moon is eclipsed in consequence of the interposition of the earth, the periphery of the earth must be the cause of this by having a spherical form. And again, from the appearance of the stars it is clear, not only that the earth is round, but that its size is not very large; for when we make a small removal to the south or the north, the circle of the horizon becomes palpably different, so that the stars overhead undergo a great change, and are not the same to those that travel in the north and to the south. For some stars are seen in Egypt or at Cyprus, but are not seen in the countries to the north of these; and the stars that in the north are visible while they make a complete circuit, there undergo a setting. So that from this it is manifest, not only that the form of the earth is round, but also that it is a part of a not very large sphere; for otherwise the difference would not be so obvious to persons making so small a change of place. Wherefore we may judge that those persons who connect the region in the neighborhood of the pillars of Hercules with that towards India, and who assert that in this way the sea is one, do not assert things very improbable. They confirm this conjecture moreover by the elephants, which are said to be of the same species towards each extreme; as if this circumstance was a consequence of the conjunction of the extremes. The mathematicians who try to calculate the measure of the circumference, make it amount to four hundred thousand stadia; whence we collect that the earth is not only spherical, but is not large compared with the magnitude of the other stars."

But in giving full meed of praise to Aristotle for the promulgation of this doctrine of the sphericity of the earth, it must unfortunately be added that the conservative philosopher paused without taking one other important step. He could not accept, but, on the contrary, he expressly repudiated, the doctrine of the earth's motion. We have seen that this idea also was a part of the Pythagorean doctrine, and we shall have occasion to dwell more at length on this point in a succeeding chapter. It has even been contended by some critics that it was the adverse conviction of the Peripatetic philosopher which, more than any other single influence, tended to retard the progress of the true doctrine regarding the mechanism of the heavens. Aristotle accepted the sphericity of the earth, and that doctrine became a commonplace of scientific knowledge, and so continued throughout classical antiquity. But Aristotle rejected the doctrine of the earth's motion, and that doctrine, though promulgated actively by a few contemporaries and immediate successors of the Stagirite, was then doomed to sink out of view for more than a thousand years. If it be a correct assumption that the influence of Aristotle was, in a large measure, responsible for this result, then we shall perhaps not be far astray in assuming that the great founder of the Peripatetic school was, on the whole, more instrumental in retarding the progress of astronomical science that any other one man that ever lived.

The field of science in which Aristotle was pre-eminently a pathfinder is zoology. His writings on natural history have largely been preserved, and they constitute by far the most important contribution to the subject that has come down to us from antiquity. They show us that Aristotle had gained possession of the widest range of facts regarding the animal kingdom, and, what is far more important, had attempted to classify these facts. In so doing he became the founder of systematic zoology. Aristotle's classification of the animal kingdom was known and studied throughout the Middle Ages, and, in fact, remained in vogue until superseded by that of Cuvier in the nineteenth century. It is not to be supposed that all the terms of Aristotle's classification originated with him. Some of the divisions are too patent to have escaped the observation of his predecessors. Thus, for example, the distinction between birds and fishes as separate classes of animals is so obvious that it must appeal to a child or to a savage. But the efforts of Aristotle extended, as we shall see, to less patent generalizations. At the very outset, his grand division of the animal kingdom into blood-bearing and bloodless animals implies a very broad and philosophical conception of the entire animal kingdom. The modern physiologist does not accept the classification, inasmuch as it is now known that colorless fluids perform the functions of blood for all the lower organisms. But the fact remains that Aristotle's grand divisions correspond to the grand divisions of the Lamarckian system—vertebrates and invertebrates—which every one now accepts. Aristotle, as we have said, based his classification upon observation of the blood; Lamarck was guided by a study of the skeleton. The fact that such diverse points of view could direct the observer towards the same result gives, inferentially, a suggestive lesson in what the modern physiologist calls the homologies of parts of the organism.

Aristotle divides his so-called blood-bearing animals into five classes: (1) Four-footed animals that bring forth their young alive; (2) birds; (3) egg-laying four-footed animals (including what modern naturalists call reptiles and amphibians); (4) whales and their allies; (5) fishes. This classification, as will be observed, is not so very far afield from the modern divisions into mammals, birds, reptiles, amphibians, and fishes. That Aristotle should have recognized the fundamental distinction between fishes and the fish-like whales, dolphins, and porpoises proves the far from superficial character of his studies. Aristotle knew that these animals breathe by means of lungs and that they produce living young. He recognized, therefore, their affinity with his first class of animals, even if he did not, like the modern naturalist, consider these affinities close enough to justify bringing the two types together into a single class.

The bloodless animals were also divided by Aristotle into five classes—namely: (1) Cephalopoda (the octopus, cuttle-fish, etc.); (2) weak-shelled animals (crabs, etc.); (3) insects and their allies (including various forms, such as spiders and centipedes, which the modern classifier prefers to place by themselves); (4) hard-shelled animals (clams, oysters, snails, etc.); (5) a conglomerate group of marine forms, including star-fish, sea-urchins, and various anomalous forms that were regarded as linking the animal to the vegetable worlds. This classification of the lower forms of animal life continued in vogue until Cuvier substituted for it his famous grouping into articulates, mollusks, and radiates; which grouping in turn was in part superseded later in the nineteenth century.

What Aristotle did for the animal kingdom his pupil, Theophrastus, did in some measure for the vegetable kingdom. Theophrastus, however, was much less a classifier than his master, and his work on botany, called *The Natural History of Development*, pays comparatively slight attention to theoretical questions. It deals largely with such practicalities as the making of charcoal, of pitch, and of resin, and the effects of various plants on the animal organism when taken as foods or as medicines. In this regard the work of Theophrastus is more nearly akin to the natural history of the famous Roman compiler, Pliny. It remained, however, throughout antiquity as the most important work on its subject, and it entitles Theophrastus to be called the "father of botany." Theophrastus deals also with the mineral kingdom after much the same fashion, and here again his work is the most notable that was produced in antiquity.

IX

GREEK SCIENCE OF THE ALEXANDRIAN OR HELLENISTIC PERIOD

WE are entering now upon the most important scientific epoch of antiquity. When Aristotle and Theophrastus passed from the scene, Athens ceased to be in any sense the scientific centre of the world. That city still retained its reminiscent glory, and cannot be ignored in the history of culture, but no great scientific leader was ever again to be born or to take up his permanent abode within the confines of Greece proper. With almost cataclysmic suddenness, a new intellectual centre appeared on the south shore of the Mediterranean. This was the city of Alexandria, a city which Alexander the Great had founded during his brief visit to Egypt, and which became the capital of Ptolemy Soter when he chose Egypt as his portion of the dismembered empire of the great Macedonian. Ptolemy had been with his master in the East, and was with him in Babylonia when he died. He had therefore come personally in contact with Babylonian civilization, and we cannot doubt that this had a most important influence upon his life, and through him upon the new civilization of the West. In point of culture, Alexandria must be regarded as the successor of Babylon, scarcely less directly than of Greece. Following the

Babylonian model, Ptolemy erected a great museum and began collecting a library. Before his death it was said that he had collected no fewer than two hundred thousand manuscripts. He had gathered also a company of great teachers and founded a school of science which, as has just been said, made Alexandria the culture-centre of the world.

Athens in the day of her prime had known nothing quite like this. Such private citizens as Aristotle are known to have had libraries, but there were no great public collections of books in Athens, or in any other part of the Greek domain, until Ptolemy founded his famous library. As is well known, such libraries had existed in Babylonia for thousands of years. The character which the Ptolemaic epoch took on was no doubt due to Babylonian influence, but quite as much to the personal experience of Ptolemy himself as an explorer in the Far East. The marvellous conquering journey of Alexander had enormously widened the horizon of the Greek geographer, and stimulated the imagination of all ranks of the people. It was but natural, then, that geography and its parent science astronomy should occupy the attention of the best minds in this succeeding epoch. In point of fact, such a company of star-gazers and earth-measurers came upon the scene in this third century B.C. as had never before existed anywhere in the world. The whole trend of the time was towards mechanics. It was as if the greatest thinkers had squarely faced about from the attitude of the mystical philosophers of the preceding century, and had set themselves the task of solving all the mechanical riddles of the universe.

They no longer troubled themselves about problems of "being" and "becoming"; they gave but little heed to metaphysical subtleties; they demanded that their thoughts should be gauged by objective realities. Hence there arose a succession of great geometers, and their conceptions were applied to the construction of new mechanical contrivances on the one hand, and to the elaboration of theories of sidereal mechanics on the other.

The wonderful company of men who performed the feats that are about to be recorded did not all find their home in Alexandria, to be sure; but they all came more or less under the Alexandrian influence. We shall see that there are two other important centres; one out in Sicily, almost at the confines of the Greek territory in the west; the other in Asia Minor, notably on the island of Samos—the island which, it will be recalled, was at an earlier day the birthplace of Pythagoras. But whereas in the previous century colonists from the confines of the civilized world came to Athens, now all eyes turned towards Alexandria, and so improved were the facilities for communication that no doubt the discoveries of one coterie of workers were known to all the others much more quickly than had ever been possible before. We learn, for example, that the studies of Aristarchus of Samos were definitely known to Archimedes of Syracuse, out in Sicily. Indeed, as we shall see, it is through a chance reference preserved in one of the writings of Archimedes that one of the most important speculations of Aristarchus is made known to us. This illustrates sufficiently the intercommunication through which the thought of the

Alexandrian epoch was brought into a single channel. We no longer, as in the day of the earlier schools of Greek philosophy, have isolated groups of thinkers. The scientific drama is now played out upon a single stage; and if we pass, as we shall in the present chapter, from Alexandria to Syracuse and from Syracuse to Samos, the shift of scenes does no violence to the dramatic unities.

Notwithstanding the number of great workers who were not properly Alexandrians, none the less the epoch is with propriety termed Alexandrian. Not merely in the third century B.C., but throughout the lapse of at least four succeeding centuries, the city of Alexander and the Ptolemies continued to hold its place as the undisputed culture-centre of the world. During that period Rome rose to its pinnacle of glory and began to decline, without ever challenging the intellectual supremacy of the Egyptian city. We shall see, in a later chapter, that the Alexandrian influences were passed on to the Mohammedan conquerors, and every one is aware that when Alexandria was finally overthrown its place was taken by another Greek city, Byzantium or Constantinople. But that transfer did not occur until Alexandria had enjoyed a longer period of supremacy as an intellectual centre than had perhaps ever before been granted to any city, with the possible exception of Babylon.

EUCLID (ABOUT 300 B.C.)

Our present concern is with that first wonderful development of scientific activity which began under the first Ptolemy, and which presents, in the course of the first century of Alexandrian influence, the most remarkable coterie of scientific workers and thinkers that antiquity produced. The earliest group of these new leaders in science had at its head a man whose name has been a household word ever since. This was Euclid, the father of systematic geometry. Tradition has preserved to us but little of the personality of this remarkable teacher; but, on the other hand, his most important work has come down to us in its entirety. The *Elements of Geometry*, with which the name of Euclid is associated in the mind of every school-boy, presented the chief propositions of its subject in so simple and logical a form that the work remained a text-book everywhere for more than two thousand years. Indeed it is only now beginning to be superseded. It is not twenty years since English mathematicians could deplore the fact that, despite certain rather obvious defects of the work of Euclid, no better text-book than this was available. Euclid's work, of course, gives expression to much knowledge that did not originate with him. We have already seen that several important propositions of geometry had been developed by Thales, and one by Pythagoras, and that the rudiments of the subject were at least as old as Egyptian civilization. Precisely how much Euclid added through his own investigations cannot be ascertained. It seems probable that he was a diffuser of knowledge rather than an originator, but as a great teacher his fame is secure. He is credited with an epigram which in itself might insure him perpetuity of fame: "There is no royal road to geometry," was his answer to Ptolemy when that ruler had questioned whether the *Elements* might not be simplified. Doubtless this, like most similar good sayings, is apocryphal; but whoever invented it has made the world his debtor.

HEROPHILUS AND ERASISTRATUS

The catholicity of Ptolemy's tastes led him, naturally enough, to cultivate the biological no less than the physical sciences. In particular his influence permitted an epochal advance in the field of medicine. Two anatomists became famous through the investigations they were permitted to make under the patronage of the enlightened ruler. These earliest of really scientific investigators of the mechanism of the human body were named Herophilus and Erasistratus. These two anatomists gained their knowledge by the dissection of human bodies (theirs are the first records that we have of such practices), and King Ptolemy himself is said to have been present at some of these dissections. They were the first to discover that the nerve-trunks have their origin in the brain and spinal cord, and they are credited also with the discovery that these nerve-trunks are of two different kinds—one to convey motor, and the other sensory impulses. They discovered, described, and named the coverings of the brain. The name of Herophilus is still applied by anatomists, in honor of the discoverer, to one of the sinuses or large canals that convey the venous blood from the head. Herophilus also noticed and described four cavities or ventricles in the brain, and reached the conclusion that one of these ventricles was the seat of the soul—a belief shared until comparatively recent times by many physiologists. He made also a careful and fairly accurate study of the anatomy of the eye, and greatly improved the old operation for cataract.

With the increased knowledge of anatomy came also corresponding advances in surgery, and many experimental operations are said to have been performed upon condemned criminals who were handed over to the surgeons by the Ptolemies. While many modern writers have attempted to discredit these assertions, it is not improbable that such operations were performed. In an age when human life was held so cheap, and among a people accustomed to torturing condemned prisoners for comparatively slight offences, it is not unlikely that the surgeons were allowed to inflict perhaps less painful tortures in the cause of science. Furthermore, we know that condemned criminals were sometimes handed over to the medical profession to be "operated upon and killed in whatever way they thought best" even as late as the sixteenth century. Tertullian[1] probably exaggerates, however, when he puts the number of such victims in Alexandria at six hundred.

Had Herophilus and Erasistratus been as happy in their deductions as to the functions of the organs as they were in their knowledge of anatomy, the science of medicine would have been placed upon a very high plane even in their time. Unfortunately, however, they not only drew erroneous inferences as to the functions of the organs, but also disagreed radically as to what functions certain organs performed, and how diseases should be treated, even when agreeing perfectly on the subject of anatomy itself. Their contribution to the knowledge of the scientific treatment of diseases holds no such place, therefore, as their anatomical investigations.

Half a century after the time of Herophilus there appeared a Greek physician, Heraclides, whose reputation in the use of drugs far surpasses that of the anatomists of the Alexandrian school. His reputation has been handed down through the centuries as that of a physician, rather than a surgeon, although in his own time he was considered one of the great surgeons of the period. Heraclides belonged to the "Empiric" school, which rejected anatomy as useless, depending entirely on the use of drugs. He is thought to have been the first physician to point out the value of opium in certain painful diseases. His prescription of this drug for certain cases of "sleeplessness, spasm, cholera, and colic," shows that his use of it was not unlike that of the modern physician in certain cases; and his treatment of fevers, by keeping the patient's head cool and facilitating the secretions of the body, is still recognized as "good practice." He advocated a free use of liquids in quenching the fever patient's thirst—a recognized therapeutic measure to-day, but one that was widely condemned a century ago.

ARCHIMEDES OF SYRACUSE AND THE FOUNDATION OF MECHANICS

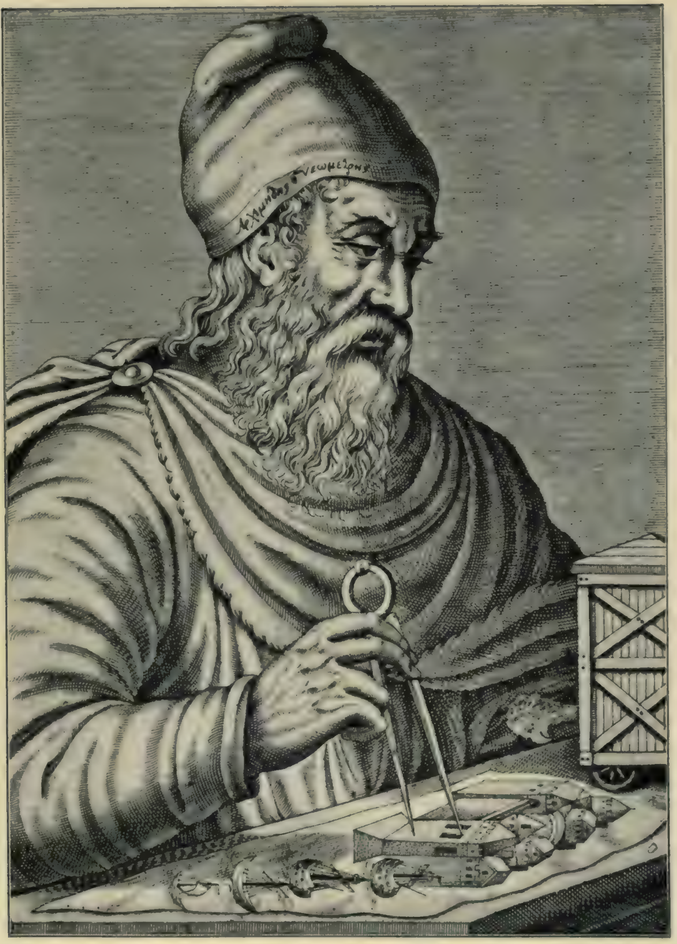
We do not know just when Euclid died, but as he was at the height of his fame in the time of Ptolemy I., whose reign ended in the year 285 B.C., it is hardly probable that he was still living when a young man named Archimedes came to Alexandria to study. Archimedes was born in the Greek colony of Syracuse, on the island of Sicily, in the year 287 B.C. When he visited Alexandria he probably found Apollonius of Perga, the pupil of Euclid, at the head of the mathematical school there. Just how long Archimedes remained at Alexandria is not known. When he had satisfied his curiosity or completed his studies, he returned to Syracuse and spent his life there, chiefly under the patronage of King Hiero, who seems fully to have appreciated his abilities.

Archimedes was primarily a mathematician. Left to his own devices, he would probably have devoted his entire time to the study of geometrical problems. But King Hiero had discovered that his protégé had wonderful mechanical ingenuity, and he made good use of this discovery. Under stress of the king's urgings, the philosopher was led to invent a great variety of mechanical contrivances, some of them most curious ones. Antiquity credited him with the invention of more than forty machines, and it is these, rather than his purely mathematical discoveries, that gave his name popular vogue both among his contemporaries and with posterity. Every one has heard of the screw of Archimedes, through which the paradoxical effect was produced of making water seem to flow up hill. The best idea of this curious mechanism is obtained if one will take in hand an ordinary corkscrew, and imagine this instrument to be changed into a hollow tube, retaining precisely the same shape but increased to some feet in length and to a proportionate diameter. If one will hold the corkscrew in a slanting direction and turn it slowly to the right, supposing that the point dips up a portion of water each time it revolves, one can in imagination follow the flow of that portion of water from spiral to spiral, the water always running downward, of course, yet paradoxically being lifted higher and higher towards the base of the corkscrew, until finally it pours out (in the actual Archimedes' tube) at the top. There is another form of the screw in which a revolving spiral blade operates within a cylinder, but the principle is precisely the same. With either form water may be lifted, by the mere turning of the screw, to any desired height. The ingenious mechanism excited the wonder of the contemporaries of Archimedes, as well it might. More efficient devices have superseded it in modern times, but it still excites the admiration of all who examine it, and its effects seem as paradoxical as ever.

Some other of the mechanisms of Archimedes have been made known to successive generations of readers through the pages of Polybius and Plutarch. These are the devices through which Archimedes aided King Hiero to ward off the attacks of the Roman general Marcellus, who in the course of the second Punic war laid siege to Syracuse.

Plutarch, in his life of Marcellus, describes the Roman's attack and Archimedes' defence in much detail. Incidentally he tells us also how Archimedes came to make the devices that rendered the siege so famous:

"Marcellus himself, with threescore galleys of five rowers at every bank, well armed and full of all sorts of artillery and fireworks, did assault by sea, and rowed hard to the wall, having made a great engine and device of battery, upon eight galleys chained together,


Ἀρχιμήδης ὁ γεωμέτρης

ARCHIMEDES

(From an old print.)

to batter the wall: trusting in the great multitude of his engines of battery, and to all such other necessary provision as he had for wars, as also in his own reputation. But Archimedes made light account of all his devices, as indeed they were nothing comparable to the engines himself had invented. This inventive art to frame instruments and engines (which are called mechanical, or organical, so highly commended and esteemed of all sorts of people) was first set forth by Architas, and by Eudoxus: partly to beautify a little the science of geometry by this fineness, and partly to prove and confirm by material examples and sensible instruments, certain geometrical conclusions, whereof a man cannot find out the conceivable demonstrations by enforced reasons and proofs. As that conclusion which instructeth one to search out two lines mean proportional, which cannot be proved by reason demonstrative, and yet notwithstanding is a principle and an accepted ground for many things which are contained in the art of portraiture. Both of them have fashioned it to the workmanship of certain instruments, called mesolabes or mesographs, which serve to find these mean lines proportional, by drawing certain curve lines, and overthwart and oblique sections. But after that Plato was offended with them, and maintained against them, that they did utterly corrupt and disgrace, the worthiness and excellence of geometry, making it to descend from things not comprehensible and without body, unto things sensible and material, and to bring it to a palpable substance, where the vile and base handiwork of man is to be employed: since that time, I say, handicraft, or the art of engines, came to be separated from geometry, and being long time despised by the philosophers, it came to be one of the warlike arts.

"But Archimedes having told King Hiero, his kinsman and friend, that it was possible to remove as great a weight as he would, with as little strength as he listed to put to it: and boasting himself thus (as they report of him) and trusting to the force of his reasons, wherewith he proved this conclusion, that if there were another globe of earth, he was able to remove this of ours, and pass it over to the other: King Hiero wondering to hear him, required him to put his device in execution, and to make him see by experience, some great or heavy weight removed, by little force. So Archimedes caught hold with a hook of one of the greatest carects, or hulks of the king (that to draw it to the shore out of the water required a marvellous number of people to go about it, and was hardly to be done so) and put a great number of men more into her, than her ordinary burden: and he himself sitting alone at his ease far off, without any straining at all, drawing the end of an engine with many wheels and pulleys, fair and softly with his hand, made it come as gently and smoothly to him, as it had floated in the sea. The king wondering to see the sight, and knowing by proof the greatness of his art; he prayed him to make him some engines, both to assault and defend, in all manner of sieges and assaults. So Archimedes made him many engines, but King Hiero never occupied any of them, because he reigned the most part of his time in peace without any wars. But this provision and munition of engines, served the Syracusan's turn marvellously at that time: and not only the provision of the engines ready made, but also the engineer and work-master himself, that had invented them.

"Now the Syracusans, seeing themselves assaulted by the Romans, both by sea and by land, were marvellously perplexed, and could not tell what to say, they were so afraid: imagining it was impossible for them to withstand so great an army. But when Archimedes fell to handling his engines, and to set them at liberty, there flew in the air infinite kinds of shot, and marvellous great stones, with an incredible noise and force on the sudden, upon the footmen that came to assault the city by land, bearing down, and tearing in pieces all those which came against them, or in what place soever they lighted, no earthly body being able to resist the violence of so heavy a weight: so that all their ranks were marvellously disordered. And as for the galleys that gave assault by sea, some were sunk with long pieces of timber like unto the yards of ships, whereto they fasten their sails, which were suddenly blown over the walls with force of their engines into their galleys, and so sunk them by their over great weight."

Polybius describes what was perhaps the most important of these contrivances, which was, he tells us, "a hand of iron, hanging by a chain from the beak of a machine, which was used in the following manner. The person who, like a pilot, guided the beak, having let fall the hand, and catched hold of the prow of any vessel, drew down the opposite end of the machine that was on the inside of the walls. And when the vessel was thus raised erect upon its stern, the machine itself was held immovable; but, the chain being suddenly loosened from the beak by the means of pulleys, some of the vessels were thrown upon their sides, others turned with the bottom upwards; and the greatest part, as the prows were plunged from a considerable height into the sea, were filled with water, and all that were on board thrown into tumult and disorder.

"Marcellus was in no small degree embarrassed," Polybius continues, "when he found himself encountered in every attempt by such resistance. He perceived that all his efforts were defeated with loss; and were even derided by the enemy. But, amidst all the anxiety that he suffered, he could not help jesting upon the inventions of Archimedes. This man, said he, employs our ships as buckets to draw water: and boxing about our sackbuts, as if they were unworthy to be associated with him, drives them from his company with disgrace. Such was the success of the siege on the side of the sea."

Subsequently, however, Marcellus took the city by strategy, and Archimedes was killed, contrary, it is said, to the express orders of Marcellus. "Syracuse being taken," says Plutarch, "nothing grieved Marcellus more than the loss of Archimedes. Who, being in his study when the city was taken, busily seeking out by himself the demonstration of some geometrical proposition which he had drawn in figure, and so earnestly occupied therein, as he neither saw nor heard any noise of enemies that ran up and down the city, and much less knew it was taken: he wondered when he saw a soldier by him, that bade him go with him to Marcellus. Notwithstanding, he spake to the soldier, and bade him tarry until he had done his conclusion, and brought it to demonstration: but the soldier being angry with his answer, drew out his sword and killed him. Others say, that the Roman soldier when he came, offered the sword's point to him, to kill him: and that Archimedes when he saw him, prayed him to hold his hand a little, that he might not leave the matter he looked for imperfect, without demonstration. But the soldier making no reckoning of his speculation, killed him presently. It is reported a third way also, saying that certain soldiers met him in the streets going to Marcellus, carrying certain mathematical instruments in a little pretty coffer, as dials for the sun, spheres, and angles, wherewith they measure the greatness of the body of the sun by view: and they supposing he had carried some gold or silver, or other precious jewels in that little coffer, slew him for it. But it is most certain that Marcellus was marvellously sorry for his death, and ever after hated the villain that slew him, as a cursed and execrable person: and how he had made also marvellous much afterwards of Archimedes' kinsmen for his sake."

We are further indebted to Plutarch for a summary of the character and influence of Archimedes, and for an interesting suggestion as to the estimate which the great philosopher put upon the relative importance of his own discoveries. "Notwithstanding Archimedes had such a great mind, and was so profoundly learned, having hidden in him the only treasure and secrets of geometrical inventions: as he would never set forth any book how to make all these warlike engines, which won him at that time the fame and glory, not of man's knowledge, but rather of divine wisdom. But he esteeming all kind of handicraft and invention to make engines, and generally all manner of sciences bringing common commodity by the use of them, to be but vile, beggarly, and mercenary dross: employed his wit and study only to write things, the beauty and subtlety whereof were not mingled anything at all with necessity. For all that he hath written, are geometrical propositions, which are without comparison of any other writings whatsoever: because the subject whereof they treat, doth appear by demonstration, the maker gives them the grace and the greatness, and the demonstration proving it so exquisitely, with wonderful reason and facility, as it is not repugnable. For in all geometry are not to be found more profound and difficult matters written, in more plain and simple terms, and by more easy principles, than those which he hath invented. Now some do impute this, to the sharpness of his wit and understanding, which was a natural gift in him: others do refer it to the extreme pains he took, which made these things come so easily from him, that they seemed as if they had been no trouble to him at all. For no man living of himself can devise the demonstration of his propositions, what pains soever he take to seek it: and yet straight so soon as he cometh to declare and open it, every man then imagineth with himself he could have found it out well enough, he can then so plainly make demonstration of the thing he meaneth to show. And therefore that methinks is likely to be true, which they write of him: that he was so ravished and drunk with the sweet enticements of this siren, which as it were lay continually with him, as he forgot his meat and drink, and was careless otherwise of himself, that oftentimes his servants got him against his will to the baths to wash and anoint him: and yet being there, he would ever be drawing out of the geometrical figures, even in the very imbers of the chimney. And while they were anointing of him with oils and sweet savours, with his finger he did draw lines upon his naked body: so far was he taken from himself, and brought into an ecstasy or trance, with the delight he had in the study of geometry, and truly ravished with the love of the Muses. But amongst many notable things he devised, it appeareth, that he most esteemed the demonstration of the proportion between the cylinder (to wit, the round column) and the sphere or globe contained in the same: for he prayed his kinsmen and friends, that after his death they would put a cylinder upon his tomb, containing a massy sphere, with an inscription of the proportion, whereof the continent exceedeth the thing contained."[2]

It should be observed that neither Polybius nor Plutarch mentions the use of burning-glasses in connection with the siege of Syracuse, nor indeed are these referred to by any other ancient writer of authority. Nevertheless, a story gained credence down to a late day to the effect that Archimedes had set fire to the fleet of the enemy with the aid of concave mirrors. An experiment was made by Sir Isaac Newton to show the possibility of a phenomenon so well in accord with the genius of Archimedes, but the silence of all the early authorities makes it more than doubtful whether any such expedient was really adopted.

It will be observed that the chief principle involved in all these mechanisms was a capacity to transmit great power through levers and pulleys, and this brings us to the most important field of the Syracusan philosopher's activity. It was as a student of the lever and the pulley that Archimedes was led to some of his greatest mechanical discoveries. He is even credited with being the discoverer of the compound pulley. More likely he was its developer only, since the principle of the pulley was known to the old Babylonians, as their sculptures testify. But there is no reason to doubt the general outlines of the story that Archimedes astounded King Hiero by proving that, with the aid of multiple pulleys, the strength of one man could suffice to drag the largest ship from its moorings.

The property of the lever, from its fundamental principle, was studied by him, beginning with the self-evident fact that "equal bodies at the ends of the equal arms of a rod, supported on its middle point, will balance each other"; or, what amounts to the same thing stated in another way, a regular cylinder of uniform matter will balance at its middle point. From this starting-point he elaborated the subject on such clear and satisfactory principles that they stand to-day practically unchanged and with few additions. From all his studies and experiments he finally formulated the principle that "bodies will be in equilibrio when their distance from the fulcrum or point of support is inversely as their weight." He is credited with having summed up his estimate of the capabilities of the lever with the well-known expression, "Give me a fulcrum on which to rest or a place on which to stand, and I will move the earth."

But perhaps the feat of all others that most appealed to the imagination of his contemporaries, and possibly also the one that had the greatest bearing upon the position of Archimedes as a scientific discoverer, was the one made familiar through the tale of the crown of Hiero. This crown, so the story goes, was supposed to be made of solid gold, but King Hiero for some reason suspected the honesty of the jeweller, and desired to know if Archimedes could devise a way of testing the question without injuring the crown. Greek imagination seldom spoiled a story in the telling, and in this case the tale was allowed to take on the most picturesque of phases. The philosopher, we are assured, pondered the problem for a long time without succeeding, but one day as he stepped into a bath, his attention was attracted by the overflow of water. A new train of ideas was started in his ever-receptive brain. Wild with enthusiasm he sprang from the bath, and, forgetting his robe, dashed along the streets of Syracuse, shouting: "Eureka! Eureka!" (I have found it!) The thought that had come into his mind was this: That any heavy substance must have a bulk proportionate to its weight; that gold and silver differ in weight, bulk for bulk, and that the way to test the bulk of such an irregular object as a crown was to immerse it in water. The experiment was made. A lump of pure gold of the weight of the crown was immersed in a certain receptacle filled with water, and the overflow noted. Then a lump of pure silver of the same weight was similarly immersed; lastly the crown itself was immersed, and of course—for the story must not lack its dramatic sequel—was found bulkier than its weight of pure gold. Thus the genius that could balk warriors and armies could also foil the wiles of the silversmith.

Whatever the truth of this picturesque narrative, the fact remains that some such experiments as these must have paved the way for perhaps the greatest of all the studies of Archimedes—those that relate to the buoyancy of water. Leaving the field of fable, we must now examine these with some precision. Fortunately, the writings of Archimedes himself are still extant, in which the results of his remarkable experiments are related, so we may present the results in the words of the discoverer.

Here they are: "First: The surface of every coherent liquid in a state of rest is spherical, and the centre of the sphere coincides with the centre of the earth. Second: A solid body which, bulk for bulk, is of the same weight as a liquid, if immersed in the liquid will sink so that the surface of the body is even with the surface of the liquid, but will not sink deeper. Third: Any solid body which is lighter, bulk for bulk, than a liquid, if placed in the liquid will sink so deep as to displace the mass of liquid equal in weight to another body. Fourth: If a body which is lighter than a liquid is forcibly immersed in the liquid, it will be pressed upward with a force corresponding to the weight of a like volume of water, less the weight of the body itself. Fifth: Solid bodies which, bulk for bulk, are heavier than a liquid, when immersed in the liquid sink to the bottom, but become in the liquid as much lighter as the weight of the displaced water itself differs from the weight of the solid." These propositions are not difficult to demonstrate, once they are conceived, but their discovery, combined with the discovery of the laws of statics already referred to, may justly be considered as proving Archimedes the most inventive experimenter of antiquity.

Curiously enough, the discovery which Archimedes himself is said to have considered the most important of all his innovations is one that seems much less striking. It is the answer to the question, What is the relation in bulk between a sphere and its circumscribing cylinder? Archimedes finds that the ratio is simply two to three. We are not informed as to how he reached his conclusion, but an obvious method would be to immerse a ball in a cylindrical cup. The experiment is one which any one can make for himself, with approximate accuracy, with the aid of a tumbler and a solid rubber ball or a billiard-ball of just the right size. Another geometrical problem which Archimedes solved was the problem as to the size of a triangle which has equal area with a circle; the answer being, a triangle having for its base the circumference of the circle and for its altitude the radius. Archimedes solved also the problem of the relation of the diameter of the circle to its circumference; his answer being a close approximation to the familiar 3.1416, which every tyro in geometry will recall as the equivalent of π.

Numerous other of the studies of Archimedes having reference to conic sections, properties of curves and spirals, and the like, are too technical to be detailed here. The extent of his mathematical knowledge, however, is suggested by the fact that he computed in great detail the number of grains of sand that would be required to cover the sphere of the sun's orbit, making certain hypothetical assumptions as to the size of the earth and the distance of the sun for the purposes of argument. Mathematicians find his computation peculiarly interesting because it evidences a crude conception of the idea of logarithms. From our present stand-point, the paper in which this calculation is contained has considerable interest because of its assumptions as to celestial mechanics. Thus Archimedes starts out with the preliminary assumption that the circumference of the earth is less than three million stadia. It must be understood that this assumption is purely for the sake of argument. Archimedes expressly states that he takes this number because it is "ten times as large as the earth has been supposed to be by certain investigators." Here, perhaps, the reference is to Eratosthenes, whose measurement of the earth we shall have occasion to revert to in a moment. Continuing, Archimedes asserts that the sun is larger than the earth, and the earth larger than the moon. In this assumption, he says, he is following the opinion of the majority of astronomers. In the third place, Archimedes assumes that the diameter of the sun is not more than thirty times greater than that of the moon. Here he is probably basing his argument upon another set of measurements of Aristarchus, to which, also, we shall presently refer more at length. In reality, his assumption is very far from the truth, since the actual diameter of the sun, as we now know, is something like four hundred times that of the moon. Fourth, the circumference of the sun is greater than one side of the thousand-faced figure inscribed in its orbit. The measurement, it is expressly stated, is based on the measurements of Aristarchus, who makes the diameter of the sun $\frac{1}{170}$ of its orbit. Archimedes adds, however, that he himself has measured the angle and that it appears to him to be less than $\frac{1}{164}$, and greater than $\frac{1}{200}$ part of the orbit. That is to say, reduced to modern terminology, he places the limit of the sun's apparent size between thirty-three minutes and twenty-seven minutes of arc. As the real diameter is thirty-two minutes, this calculation is surprisingly exact, considering the implements then at command. But the honor of first making it must be given to Aristarchus and not to Archimedes.

We need not follow Archimedes to the limits of his incomprehensible numbers of sand-grains. The calculation is chiefly remarkable because it was made before the introduction of the so-called Arabic numerals had simplified mathematical calculations. It will be recalled that the Greeks used letters for numerals, and, having no cipher, they soon found themselves in difficulties when large numbers were involved. The Roman system of numerals simplified the matter somewhat, but the beautiful simplicity of the decimal system did not come into vogue until the Middle Ages, as we shall see. Notwithstanding the difficulties, however, Archimedes followed out his calculations to the piling up of bewildering numbers, which the modern mathematician finds to be the consistent outcome of the problem he had set himself.

But it remains to notice the most interesting feature of this document in which the calculation of the sand-grains is contained. "It was known to me," says Archimedes, "that most astronomers understand by the expression 'world' (universe) a ball of which the centre is the middle point of the earth, and of which the radius is a straight line between the centre of the earth and the sun." Archimedes himself appears to accept this opinion of the majority,—it at least serves as well as the contrary hypothesis for the purpose of his calculation,—but he goes on to say: "Aristarchus of Samos, in his writing against the astronomers, seeks to establish the fact that the world is really very different from this. He holds the opinion that the fixed stars and the sun are immovable and that the earth revolves in a circular line about the sun, the sun being at the centre of this circle." This remarkable bit of testimony establishes beyond question the position of Aristarchus of Samos as the Copernicus of antiquity. We must make further inquiry as to the teachings of the man who had gained such a remarkable insight into the true system of the heavens.

ARISTARCHUS OF SAMOS, THE COPERNICUS OF ANTIQUITY

It appears that Aristarchus was a contemporary of Archimedes, but the exact dates of his life are not known. He was actively engaged in making astronomical observations in Samos somewhat before the middle of the third century B.C.; in other words, just at the time when the activities of the Alexandrian school were at their height. Hipparchus, at a later day, was enabled to compare his own observations with those made by Aristarchus, and, as we have just seen, his work was well known to so distant a contemporary as Archimedes. Yet the facts of his life are almost a blank for us, and of his writings only a single one has been preserved. That one, however, is a most important and interesting paper on the measurements of the sun and the moon. Unfortunately, this paper gives us no direct clew as to the opinions of Aristarchus concerning the relative positions of the earth and sun. But the testimony of Archimedes as to this is unequivocal, and this testimony is supported by other rumors in themselves less authoritative.

In contemplating this astronomer of Samos, then, we are in the presence of a man who had solved in its essentials the problem of the mechanism of the solar system. It appears from the words of Archimedes that Aristarchus had propounded his theory in explicit writings. Unquestionably, then, he held to it as a positive doctrine, not as a mere vague guess. We shall show, in a moment, on what grounds he based his opinion. Had his teaching found vogue, the story of science would be very different from what it is. We should then have no tale to tell of a Copernicus coming upon the scene fully seventeen hundred years later with the revolutionary doctrine that our world is not the centre of the universe. We should not have to tell of the persecution of a Bruno or of a Galileo for teaching this doctrine in the seventeenth century of an era which did not begin till two hundred years after the death of Aristarchus. But, as we know, the teaching of the astronomer of Samos did not win its way. The old conservative geocentric doctrine, seemingly so much more in accordance with the every-day observations of mankind, supported by the majority of astronomers with the Peripatetic philosophers at their head, held its place. It found fresh supporters presently among the later Alexandrians, and so fully eclipsed the heliocentric view that we should scarcely know that view had even found an advocate were it not for here and there such a chance record as the phrases we have just quoted from Archimedes. Yet, as we now see, the heliocentric doctrine, which we know to be true, had been thought out and advocated as the correct theory of celestial mechanics by at least one worker of the third century B.C. Such an idea, we may be sure, did not spring into the mind of its originator except as the culmination of a long series of observations and inferences. The precise character of the evolution we perhaps cannot trace, but its broader outlines are open to our observation, and we may not leave so important a topic without at least briefly noting them.

Fully to understand the theory of Aristarchus, we must go back a century or two and recall that as long ago as the time of that other great native of Samos, Pythagoras, the conception had been reached that the earth is in motion. We saw, in dealing with Pythagoras, that we could not be sure as to precisely what he himself taught, but there is no question that the idea of the world's motion became from an early day a so-called Pythagorean doctrine. While all the other philosophers, so far as we know, still believed that the world was flat, the Pythagoreans out in Italy taught that the world is a sphere and that the apparent motions of the heavenly bodies are really due to the actual motion of the earth itself. They did not, however, vault to the conclusion that this true motion of the earth takes place in the form of a circuit about the sun. Instead of that, they conceived the central body of the universe to be a great fire, invisible from the earth, because the inhabited side of the terrestrial ball was turned away from it. The sun, it was held, is but a great mirror, which reflects the light from the central fire. Sun and earth alike revolve about this great fire, each in its own orbit. Between the earth and the central fire there was, curiously enough, supposed to be an invisible earthlike body which was given the name of Anticthon, or counter-earth. This body, itself revolving about the central fire, was supposed to shut off the central light now and again from the sun or from the moon, and thus to account for certain eclipses for which the shadow of the earth did not seem responsible. It was, perhaps, largely to account for such eclipses that the counter-earth was invented. But it is supposed that there was another reason. The Pythagoreans held that there is a peculiar sacredness in the number ten. Just as the Babylonians of the early day and the Hegelian philosophers of a more recent epoch saw a sacred connection between the number seven and the number of planetary bodies, so the Pythagoreans thought that the universe must be arranged in accordance with the number ten. Their count of the heavenly bodies, including the sphere of the fixed stars, seemed to show nine, and the counter-earth supplied the missing body.

The precise genesis and development of this idea cannot now be followed, but that it was prevalent about the fifth century B.C. as a Pythagorean doctrine cannot be questioned. Anaxagoras also is said to have taken account of the hypothetical counter-earth in his explanation of eclipses; though, as we have seen, he probably did not accept that part of the doctrine which held the earth to be a sphere. The names of Philolaus and Heraclides have been linked with certain of these Pythagorean doctrines. Eudoxus, too, who, like the others, lived in Asia Minor in the fourth century B.C., was held to have made special studies of the heavenly spheres and perhaps to have taught that the earth moves. So, too, Nicetas must be named among those whom rumor credited with having taught that the world is in motion. In a word, the evidence, so far as we can garner it from the remaining fragments, tends to show that all along, from the time of the early Pythagoreans, there had been an undercurrent of opinion in the philosophical world which questioned the fixity of the earth; and it would seem that the school of thinkers who tended to accept the revolutionary view centred in Asia Minor, not far from the early home of the founder of the Pythagorean doctrines. It was not strange, then, that the man who was finally to carry these new opinions to their logical conclusion should hail from Samos.

But what was the support which observation could give to this new, strange conception that the heavenly bodies do not in reality move as they seem to move, but that their apparent motion is due to the actual revolution of the earth? It is extremely difficult for any one nowadays to put himself in a mental position to answer this question. We are so accustomed to conceive the solar system as we know it to be, that we are wont to forget how very different it is from what it seems. Yet one needs but to glance up at the sky, and then to glance about one at the solid earth, to grant, on a moment's reflection, that the geocentric idea is of all others the most natural; and that to conceive the sun as the actual centre of the solar system is an idea which must look for support to some other evidence than that which ordinary observation can give. Such was the view of most of the ancient philosophers, and such continued to be the opinion of the majority of mankind long after the time of Copernicus. We must not forget that even so great an observing astronomer as Tycho Brahe, so late as the seventeenth century, declined to accept the heliocentric theory, though admitting that all the planets except the earth revolve about the sun. We shall see that before the Alexandrian school lost its influence a geocentric scheme had been evolved which fully explained all the apparent motions of the heavenly bodies. All this, then, makes us but wonder the more that the genius of an Aristarchus could give precedence to scientific induction as against the seemingly clear evidence of the senses.

What, then, was the line of scientific induction that led Aristarchus to this wonderful goal? Fortunately, we are able to answer that query, at least in part. Aristarchus gained his evidence through some wonderful measurements. First, he measured the disks of the sun and the moon. This, of course, could in itself give him no clew to the distance of these bodies, and therefore no clew as to their relative size; but in attempting to obtain such a clew he hit upon a wonderful yet altogether simple experiment. It occurred to him that when the moon is precisely dichotomized—that is to say, precisely at the half—the line of vision from the earth to the moon must be precisely at right-angles with the line of light passing from the sun to the moon. At this moment, then, the imaginary lines joining the sun, the moon, and the earth, make a right-angle triangle. But the properties of the right-angle triangle had long been studied and were well understood. One acute angle of such a triangle determines the figure of the triangle itself. We have already seen that Thales, the very earliest of the Greek philosophers, measured the distance of a ship at sea by the application of this principle. Now Aristarchus sights the sun in place of Thales' ship, and, sighting the moon at the same time, measures the angle and establishes the shape of his right-angle triangle. This does not tell him the distance of the sun, to be sure, for he does not know the length of his base-line—that is to say, of the line between the moon and the earth. But it does establish the relation of that base-line to the other lines of the triangle; in other words, it tells him the distance of the sun in terms of the moon's distance. As Aristarchus strikes the angle, it shows that the sun is eighteen times as distant as the moon. Now, by comparing the apparent size of the sun with the apparent size of the moon—which, as we have seen, Aristarchus has already measured—he is able to tell us that the

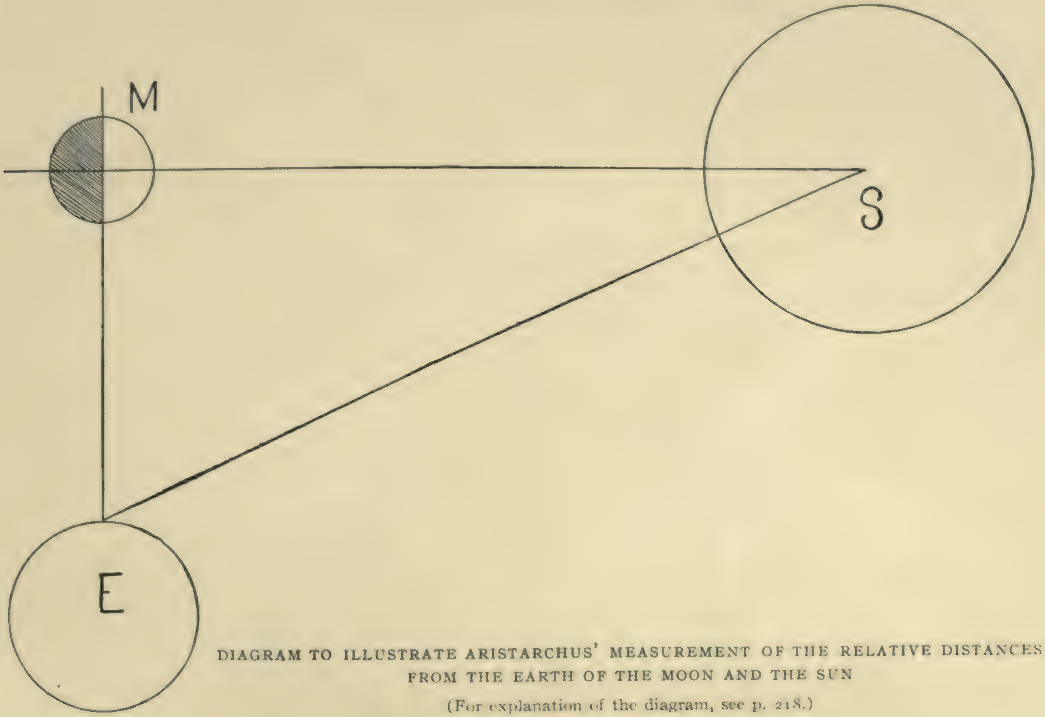


DIAGRAM TO ILLUSTRATE ARISTARCHUS' MEASUREMENT OF THE RELATIVE DISTANCES FROM THE EARTH OF THE MOON AND THE SUN

(For explanation of the diagram, see p. 218.)

sun is "more than 5832 times, and less than 8000" times larger than the moon; though his measurements, taken by themselves, give no clew to the actual bulk of either body. These conclusions, be it understood, are absolutely valid inferences—nay, demonstrations—from the measurements involved, provided only that these measurements have been correct. Unfortunately, the angle of the triangle we have just seen measured is exceedingly difficult to determine with accuracy, while at the same time, as a moment's reflection will show, it is so large an angle that a very slight deviation from the truth will greatly affect the distance at which its line joins the other side of the triangle. Then again, it is virtually impossible to tell the precise moment when the moon is at half, as the line it gives is not so sharp that we can fix it with absolute accuracy. There is, moreover, another element of error due to the refraction of light by the earth's atmosphere. The experiment was probably made when the sun was near the horizon, at which time, as we now know, but as Aristarchus probably did not suspect, the apparent displacement of the sun's position is considerable; and this displacement, it will be observed, is in the direction to lessen the angle in question.

In point of fact, Aristarchus estimated the angle at eighty-seven degrees. Had his instrument been more precise, and had he been able to take account of all the elements of error, he would have found it eighty-seven degrees and fifty-two minutes. The difference of measurement seems slight; but it sufficed to make the computations differ absurdly from the truth. The sun is really not merely eighteen times but more than two hundred times the distance of the moon, as Wendelein discovered on repeating the experiment of Aristarchus about two thousand years later. Yet this discrepancy does not in the least take away from the validity of the method which Aristarchus employed. Moreover, his conclusion, stated in general terms, was perfectly correct: the sun is many times more distant than the moon and vastly larger than that body. Granted, then, that the moon is, as Aristarchus correctly believed, considerably less in size than the earth, the sun must be enormously larger than the earth; and this is the vital inference which, more than any other, must have seemed to Aristarchus to confirm the suspicion that the sun and not the earth is the centre of the planetary system. It seemed to him inherently improbable that an enormously large body like the sun should revolve about a small one such as the earth. And again, it seemed inconceivable that a body so distant as the sun should whirl through space so rapidly as to make the circuit of its orbit in twenty-four hours. But, on the other hand, that a small body like the earth should revolve about the gigantic sun seemed inherently probable. This proposition granted, the rotation of the earth on its axis follows as a necessary consequence in explanation of the seeming motion of the stars. Here, then, was the heliocentric doctrine reduced to a virtual demonstration by Aristarchus of Samos, somewhere about the middle of the third century B.C.

It must be understood that in following out the steps of reasoning by which we suppose Aristarchus to have reached so remarkable a conclusion, we have to some extent guessed at the processes of thought-development; for no line of explication written by the astronomer himself on this particular point has come down to us. There does exist, however, as we have already stated, a very remarkable treatise by Aristarchus on the *Size and Distance of the Sun and the Moon*, which so clearly suggests the methods of reasoning of the great astronomer, and so explicitly cites the results of his measurements, that we cannot well pass it by without quoting from it at some length. It is certainly one of the most remarkable scientific documents of antiquity. As already noted, the heliocentric doctrine is not expressly stated here. It seems to be tacitly implied throughout, but it is not a necessary consequence of any of the propositions expressly stated. These propositions have to do with certain observations and measurements and what Aristarchus believes to be inevitable deductions from them, and he perhaps did not wish to have these deductions challenged through associating them with a theory which his contemporaries did not accept. In a word, the paper of Aristarchus is a rigidly scientific document unvitiated by association with any theorizings that are not directly germane to its central theme. The treatise opens with certain hypotheses as follows:

"First. The moon receives its light from the sun.

"Second. The earth may be considered as a point and as the centre of the orbit of the moon.

"Third. When the moon appears to us dichotomized it offers to our view a great circle [or actual meridian] of its circumference which divides the illuminated part from the dark part.

"Fourth. When the moon appears dichotomized its distance from the sun is less than a quarter oı the circumference [of its orbit] by a thirtieth part of that quarter."

That is to say, in modern terminology, the moon at this time lacks three degrees (one thirtieth of ninety degrees) of being at right angles with the line of the sun as viewed from the earth; or, stated otherwise, the angular distance of the moon from the sun as viewed from the earth is at this time eighty-seven degrees—this being, as we have already observed, the fundamental measurement upon which so much depends. We may fairly suppose that some previous paper of Aristarchus's has detailed the measurement which here is taken for granted, yet which of course could depend solely on observation.

"Fifth. The diameter of the shadow [cast by the earth at the point where the moon's orbit cuts that shadow when the moon is eclipsed] is double the diameter of the moon."

Here again a knowledge of previously established measurements is taken for granted; but, indeed, this is the case throughout the treatise.

"Sixth. The arc subtended in the sky by the moon is a fifteenth part of a sign" of the zodiac; that is to say, since there are twenty-four, signs in the zodiac, one-fifteenth of one twenty-fourth, or in modern terminology, one degree of arc. This is Aristarchus's measurement of the moon to which we have already referred when speaking of the measurements of Archimedes.

"If we admit these six hypotheses," Aristarchus continues, "it follows that the sun is more than eighteen times more distant from the earth than is the moon, and that it is less than twenty times more distant, and that the diameter of the sun bears a corresponding relation to the diameter of the moon; which is proved by the position of the moon when dichotomized. But the ratio of the diameter of the sun to that of the earth is greater than nineteen to three and less than forty-three to six. This is demonstrated by the relation of the distances, by the position [of the moon] in relation to the earth's shadow, and by the fact that the arc subtended by the moon is a fifteenth part of a sign."

Aristarchus follows with nineteen propositions intended to elucidate his hypotheses and to demonstrate his various contentions. These show a singularly clear grasp of geometrical problems and an altogether correct conception of the general relations as to size and position of the earth, the moon, and the sun. His reasoning has to do largely with the shadow cast by the earth and by the moon, and it presupposes a considerable knowledge of the phenomena of eclipses. His first proposition is that "two equal spheres may always be circumscribed in a cylinder; two unequal spheres in a cone of which the apex is found on the side of the smaller sphere; and a straight line joining the centres of these spheres is perpendicular to each of the two circles made by the contact of the surface of the cylinder or of the cone with the spheres."

It will be observed that Aristarchus has in mind here the moon, the earth, and the sun as spheres to be circumscribed within a cone, which cone is made tangible and measurable by the shadows cast by the non-luminous bodies; since, continuing, he clearly states in proposition nine, that "when the sun is totally eclipsed, an observer on the earth's surface is at an apex of a cone comprising the moon and the sun." Various propositions deal with other relations of the shadows which need not detain us since they are not fundamentally important, and we may pass to the final conclusions of Aristarchus, as reached in his propositions ten to nineteen.

Now, since (proposition ten) "the diameter of the sun is more than eighteen times and less than twenty times greater than that of the moon," it follows (proposition eleven) "that the bulk of the sun is to that of the moon in ratio, greater than 5832 to 1, and less than 8000 to 1."

"Proposition sixteen. The diameter of the sun is to the diameter of the earth in greater proportion than nineteen to three, and less than forty-three to six.

"Proposition seventeen. The bulk of the sun is to that of the earth in greater proportion than 6859 to 27, and less than 79,507 to 216.

"Proposition eighteen. The diameter of the earth is to the diameter of the moon in greater proportion than 108 to 43 and less than 60 to 19.

"Proposition nineteen. The bulk of the earth is to that of the moon in greater proportion than 1,259,712 to 79,507 and less than 216,000 to 6859."

Such then are the more important conclusions of this very remarkable paper—a paper which seems to have interest to the successors of Aristarchus generation after generation, since this alone of all the writings of the great astronomer has been preserved. How widely the exact results of the measurements of Aristarchus differ from the truth, we have pointed out as we progressed. But let it be repeated that this detracts little from the credit of the astronomer who had such clear and correct conceptions of the relations of the heavenly bodies and who invented such correct methods of measurement. Let it be particularly observed, however, that all the conclusions of Aristarchus are stated in relative terms. He nowhere attempts to estimate the precise size of the earth, of the moon, or of the sun, or the actual distance of one of these bodies from another. The obvious reason for this is that no data were at hand from which to make such precise measurements. Had Aristarchus known the size of any one of the bodies in question, he might readily, of course, have determined the size of the others by the mere application of his relative scale; but he had no means of determining the size of the earth, and to this extent his system of measurements remained imperfect. Where Aristarchus halted, however, another worker of the same period took the task in hand and by an altogether wonderful measurement determined the size of the earth, and thus brought the scientific theories of cosmology to their climax. This worthy supplementor of the work of Aristarchus was Eratosthenes of Alexandria.

ERATOSTHENES, "THE SURVEYOR OF THE WORLD"

An altogether remarkable man was this native of Cyrene, who came to Alexandria from Athens to be the chief librarian of Ptolemy Euergetes. He was not merely an astronomer and a geographer, but a poet and grammarian as well. His contemporaries jestingly called him Beta the Second, because he was said through the universality of his attainments to be "a second Plato" in philosophy, "a second Thales" in astronomy, and so on throughout the list. He was also called the "surveyor of the world," in recognition of his services to geography. Hipparchus said of him, perhaps half jestingly, that he had studied astronomy as a geographer and geography as an astronomer. It is not quite clear whether the epigram was meant as compliment or as criticism. Similar phrases have been turned against men of versatile talent in every age. Be that as it may, Eratosthenes passed into history as the father of scientific geography and of scientific chronology; as the astronomer who first measured the obliquity of the ecliptic; and as the inventive genius who performed the astounding feat of measuring the size of the globe on which we live at a time when only a relatively small portion of that globe's surface was known to civilized man. It is no discredit to approach astronomy as a geographer and geography as an astonomer if the results are such as these. What Eratosthenes really did was to approach both astronomy and geography from two seemingly divergent points of attack—namely, from the stand-point of the geometer and also from that of the poet. Perhaps no man in any age has brought a better combination of observing and imaginative faculties to the aid of science.

Nearly all the discoveries of Eratosthenes are associated with observations of the shadows cast by the sun. We have seen that, in the study of the heavenly bodies, much depends on the measurement of angles. Now the easiest way in which angles can be measured, when solar angles are in question, is to pay attention, not to the sun itself, but to the shadow that it casts. We saw that Thales made some remarkable measurements with the aid of shadows, and we have more than once referred to the gnomon, which is the most primitive, but which long remained the most important, of astronomical instruments. It is believed that Eratosthenes invented an important modification of the gnomon which was elaborated afterwards by Hipparchus and called an armillary sphere. This consists essentially of a small gnomon, or perpendicular post, attached to a plane representing the earth's equator and a hemisphere in imitation of the earth's surface. With the aid of this, the shadow cast by the sun could be very accurately measured. It involves no new principle. Every perpendicular post or object of any kind placed in the sunlight casts a shadow from which the angles now in question could be roughly measured. The province of the armillary sphere was to make these measurements extremely accurate.

With the aid of this implement, Eratosthenes carefully noted the longest and the shortest shadows cast by the gnomon—that is to say, the shadows cast on the days of the solstices. He found that the distance between the tropics thus measured represented 47° 42′ 39″ of arc. One-half of this, or 23° 51′ 19.5″, represented the obliquity of the ecliptic—that is to say, the angle by which the earth's axis dipped from the perpendicular with reference to its orbit. This was a most important observation, and because of its accuracy it has served modern astronomers well for comparison in measuring the trifling change due to our earth's slow, swinging wobble. For the earth, be it understood, like a great top spinning through space, holds its position with relative but not quite absolute fixity. It must not be supposed, however, that the experiment in question was quite new with Eratosthenes. His merit consists rather in the accuracy with which he made his observation than in the novelty of the conception; for it is recorded that Eudoxus, a full century earlier, had remarked the obliquity of the ecliptic. That observer had said that the obliquity corresponded to the side of a pentadecagon, or fifteen-sided figure, which is equivalent in modern phraseology to twenty-four degrees of arc. But so little is known regarding the way in which Eudoxus reached his estimate that the measurement of Eratosthenes is usually spoken of as if it were the first effort of the kind.

Much more striking, at least in its appeal to the popular imagination, was that other great feat which Eratosthenes performed with the aid of his perfected gnomon—the measurement of the earth itself. When we reflect that at this period the portion of the earth open to observation extended only from the Straits of Gibraltar on the west to India on the east, and from the North Sea to Upper Egypt, it certainly seems enigmatical—at first thought almost miraculous—that an observer should have been able to measure the entire globe. That he should have accomplished this through observation of nothing more than a tiny bit of Egyptian territory and a glimpse of the sun's shadow makes it seem but the more wonderful. Yet the method of Eratosthenes, like many another enigma, seems simple enough once it is explained. It required but the application of a very elementary knowledge of the geometry of circles, combined with the use of a fact or two from local geography—which detracts nothing from the genius of the man who could reason from such simple premises to so wonderful a conclusion.

Stated in a few words, the experiment of Eratosthenes was this. His geographical studies had taught him that the town of Syene lay directly south of Alexandria, or, as we should say, on the same meridian of latitude. He had learned, further, that Syene lay directly under the tropic, since it was reported that at noon on the day of the summer solstice the gnomon there cast no shadow, while a deep well was illumined to the bottom by the sun. A third item of knowledge, supplied by the surveyors of Ptolemy, made the distance between Syene and Alexandria five thousand stadia. These, then, were the preliminary data required by Eratosthenes. Their significance consists in the fact that here is a measured bit of the earth's arc five thousand stadia in length. If we could find out what angle that bit of arc subtends, a mere matter of multiplication would give us the size of the earth. But how determine this all-important number? The answer came through reflection on the relations of concentric circles. If you draw any number of circles, of whatever size, about a given centre, a pair of radii drawn from that centre will cut arcs of the same relative size from all the circles. One circle may be so small that the actual arc subtended by the radii in a given case may be but an inch in length, while another circle is so large that its corresponding arc is measured in millions of miles; but in each case the same number of so-called degrees will represent the relation of each arc to its circumference. Now, Eratosthenes knew, as just stated, that the sun, when on the meridian on the day of the summer solstice, was directly over the town of Syene. This meant that at that moment a radius of the earth projected from Syene would point directly towards the sun. Meanwhile, of course, the zenith would represent the projection of the radius of the earth passing through Alexandria. All that was required, then, was to measure, at Alexandria, the angular distance of the sun from the zenith at noon on the day of the solstice to secure an approximate measurement of the arc of the sun's circumference, corresponding to the arc of the earth's surface represented by the measured distance between Alexandria and Syene.

The reader will observe that the measurement could not be absolutely accurate, because it is made from the surface of the earth, and not from the earth's centre, but the size of the earth is so insignificant in comparison with the distance of the sun that this slight discrepancy could be disregarded.

The way in which Eratosthenes measured this angle was very simple. He merely measured the angle of the shadow which his perpendicular gnomon at Alexandria cast at mid-day on the day of the solstice, when, as already noted, the sun was directly perpendicular at Syene. Now a glance at the diagram will make it clear that the measurement of

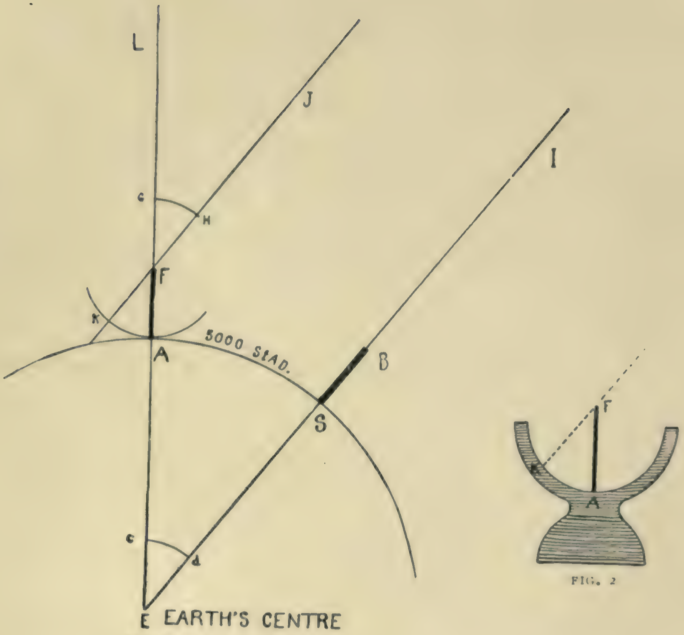


FIG. 1

DIAGRAM TO ILLUSTRATE ERATOSTHENES' MEASUREMENT OF THE GLOBE

FIG. 1. AF is a gnomon at Alexandria; SB a gnomon at Syene; IS and JK represent the sun's rays. The angle actually measured by Eratosthenes is KFA, as determined by the shadow cast by the gnomon AF. This angle is equal to the opposite angle JFL, which measures the sun's distance from the zenith; and which is also equal to the angle AES—to determine the size of which is the real object of the entire measurement.

FIG. 2 shows the form of the gnomon actually employed in antiquity. The hemisphere KA being marked with a scale, it is obvious that in actual practice Eratosthenes required only to set his gnomon in the sunlight at the proper moment, and read off the answer to his problem at a glance. The simplicity of the method makes the result seem all the more wonderful.

this angle of the shadow is merely a convenient means of determining the precisely equal opposite angle subtending an arc of an imaginary circle passing through the sun; the arc which, as already explained, corresponds with the arc of the earth's surface represented by the distance between Alexandria and Syene. He found this angle to represent 7° 12′, or one-fiftieth of the circle. Five thousand stadia, then, represent one-fiftieth of the earth's circumference; the entire circumference being, therefore, 250,000 stadia. Unfortunately, we do not know which one of the various measurements used in antiquity is represented by the stadia of Eratosthenes. According to the researches of Lepsius, however, the stadium in question represented 180 meters, and this would make the earth, according to the measurement of Eratosthenes, about twenty-eight thousand miles in circumference, an answer sufficiently exact to justify the wonder which the experiment excited in antiquity, and the admiration with which it has ever since been regarded.

Of course it is the method, and not its details or its exact results, that excites our interest. And beyond question the method was an admirable one. Its result, however, could not have been absolutely accurate, because, while correct in principle, its data were defective. In point of fact Syene did not lie precisely on the same meridian as Alexandria, neither did it lie exactly on the tropic. Here, then, are two elements of inaccuracy. Moreover, it is doubtful whether Eratosthenes made allowance, as he should have done, for the semi-diameter of the sun in measuring the angle of the shadow. But these are mere details, scarcely worthy of mention from our present stand-point. What perhaps is deserving of more attention is the fact that this epoch-making measurement of Eratosthenes may not have been the first one to be made. A passage of Aristotle records that the size of the earth was said to be 400,000 stadia. Some commentators have thought that Aristotle merely referred to the area of the inhabited portion of the earth and not to the circumference of the earth itself, but his words seem doubtfully susceptible of this interpretation; and if he meant, as his words seem to imply, that philosophers of his day had a tolerably precise idea of the globe, we must assume that this idea was based upon some sort of measurement. The recorded size, 400,000 stadia, is a sufficient approximation to the truth to suggest something more than a mere unsupported guess. Now, since Aristotle died more than fifty years before Eratosthenes was born, his report as to the alleged size of the earth certainly has a suggestiveness that cannot be overlooked; but it arouses speculations without giving an inkling as to their solution. If Eratosthenes had a precursor as an earth-measurer, no hint or rumor has come down to us that would enable us to guess who that precursor may have been. His personality is as deeply enveloped in the mists of the past as are the personalities of the great prehistoric discoverers. For the purpose of the historian, Eratosthenes must stand as the inventor of the method with which his name is associated, and as the first man of whom we can say with certainty that he measured the size of the earth. Right worthily, then, had the

Alexandrian philosopher won his proud title of "surveyor of the world."

HIPPARCHUS, "THE LOVER OF TRUTH"

Eratosthenes outlived most of his great contemporaries. He saw the turning of that first and greatest century of Alexandrian science, the third century before our era. He died in the year 196 B.C., having, it is said, starved himself to death to escape the miseries of blindness;—to the measurer of shadows, life without light seemed not worth the living. Eratosthenes left no immediate successor. A generation later, however, another great figure appeared in the astronomical world in the person of Hipparchus, a man who, as a technical observer, had perhaps no peer in the ancient world: one who set so high a value upon accuracy of observation as to earn the title of "the lover of truth." Hipparchus was born at Nicæa, in Bithynia, in the year 160 B.C. His life, all too short for the interests of science, ended in the year 125 B.C. The observations of the great astronomer were made chiefly, perhaps entirely, at Rhodes. A misinterpretation of Ptolemy's writings led to the idea that Hipparchus performed his chief labors in Alexandria, but it is now admitted that there is no evidence for this. Delambre doubted, and most subsequent writers follow him here, whether Hipparchus ever so much as visited Alexandria. In any event there seems to be no question that Rhodes may claim the honor of being the chief site of his activities.

It was Hipparchus whose somewhat equivocal comment on the work of Eratosthenes we have already noted. No counter-charge in kind could be made against the critic himself; he was an astronomer pure and simple. His gift was the gift of accurate observation rather than the gift of imagination. No scientific progress is possible without scientific guessing, but Hipparchus belonged to that class of observers with whom hypothesis is held rigidly subservient to fact. It was not to be expected that his mind would be attracted by the heliocentric theory of Aristarchus. He used the facts and observations gathered by his great predecessor of Samos, but he declined to accept his theories. For him the world was central; his problem was to explain, if he could, the irregularities of motion which sun, moon, and planets showed in their seeming circuits about the earth. Hipparchus had the gnomon of Eratosthenes—doubtless in a perfected form—to aid him, and he soon proved himself a master in its use. For him, as we have said, accuracy was everything; this was the one element that led to all his great successes.

Perhaps his greatest feat was to demonstrate the eccentricity of the sun's seeming orbit. We of to-day, thanks to Keppler and his followers, know that the earth and the other planetary bodies in their circuit about the sun describe an ellipse and not a circle. But in the day of Hipparchus, though the ellipse was recognized as a geometrical figure (it had been described and named along with the parabola and hyperbola by Apollonius of Perga, the pupil of Euclid), yet it would have been the rankest heresy to suggest an elliptical course for any heavenly body. A metaphysical theory, as propounded perhaps by the Pythagoreans but ardently supported by Aristotle, declared that the circle is the perfect figure, and pronounced it inconceivable that the motions of the spheres should be other than circular. This thought dominated the mind of Hipparchus, and so when his careful measurements led him to the discovery that the northward and southward journeyings of the sun did not divide the year into four equal parts, there was nothing open to him but to either assume that the earth does not lie precisely at the centre of the sun's circular orbit or to find some alternative hypothesis.

In point of fact, the sun (reversing the point of view in accordance with modern discoveries) does lie at one focus of the earth's elliptical orbit, and therefore away from the physical centre of that orbit; in other words, the observations of Hipparchus were absolutely accurate. He was quite correct in finding that the sun spends more time on one side of the equator than on the other. When, therefore, he estimated the relative distance of the earth from the geometrical centre of the sun's supposed circular orbit, and spoke of this as the measure of the sun's eccentricity, he propounded a theory in which true data of observation were curiously mingled with a positively inverted theory. That the theory of Hipparchus was absolutely consistent with all the facts of this particular observation is the best evidence that could be given of the difficulties that stood in the way of a true explanation of the mechanism of the heavens.

But it is not merely the sun which was observed to vary in the speed of its orbital progress; the moon and the planets also show curious accelerations and retardations of motion. The moon in particular received most careful attention from Hipparchus. Dominated by his conception of the perfect spheres, he could find but one explanation of the anomalous motions which he observed, and this was to assume that the various heavenly bodies do not fly on in an unvarying arc in their circuit about the earth, but describe minor circles as they go which can be likened to nothing so tangibly as to a light attached to the rim of a wagon-wheel in motion. If such an invisible wheel be imagined as carrying the sun, for example, on its rim, while its invisible hub follows unswervingly the circle of the sun's mean orbit (this wheel, be it understood, lying in the plane of the orbit, not at right-angles to it), then it must be obvious that while the hub remains always at the same distance from the earth, the circling rim will carry the sun nearer the earth, then farther away, and that while it is traversing that portion of the arc which brings it towards the earth, the actual forward progress of the sun will be retarded notwithstanding the uniform motion of the hub, just as it will be accelerated in the opposite arc. Now, if we suppose our sun-bearing wheel to turn so slowly that the sun revolves but once about its imaginary hub while the wheel itself is making the entire circuit of the orbit, we shall have accounted for the observed fact that the sun passes more quickly through one-half of the orbit than through the other. Moreover, if we can visualize the process and imagine the sun to have left a visible line of fire behind him throughout the course, we shall see that in reality the two circular motions involved have really resulted in producing an elliptical orbit.

The idea is perhaps made clearer if we picture the actual progress of the lantern attached to the rim of an ordinary cart-wheel. When the cart is drawn forward the lantern is made to revolve in a circle as regards the hub of the wheel, but since that hub is constantly going forward, the actual path described by the lantern is not a circle at all but a waving line. It is precisely the same with the imagined course of the sun in its orbit, only that we view these lines just as we should view the lantern on the wheel if we looked at it from directly above and not from the side. The proof that the sun is describing this waving line, and therefore must be considered as attached to an imaginary wheel, is furnished, as it seemed to Hipparchus, by the observed fact of the sun's varying speed.

That is one way of looking at the matter. It is an hypothesis that explains the observed facts—after a fashion, and indeed a very remarkable fashion. The idea of such an explanation did not originate with Hipparchus. The germs of the thought were as old as the Pythagorean doctrine that the earth revolves about a centre that we cannot see. Eudoxus gave the conception greater tangibility, and may be considered as the father of this doctrine of wheels—epicycles, as they came to be called. Two centuries before the time of Hipparchus he conceived a doctrine of spheres which Aristotle found most interesting, and which served to explain, along the lines we have just followed, the observed motions of the heavenly bodies. Calippus, the reformer of the calendar, is said to have carried an account of this theory to Aristotle. As new irregularities of motion of the sun, moon, and planetary bodies were pointed out, new epicycles were invented. There is no limit to the number of imaginary circles that may be inscribed about an imaginary centre, and if we conceive each one of these circles to have a proper motion of its own, and each one to carry the sun in the line of that motion, except as it is diverted by the other motions—if we can visualize this complex mingling of wheels—we shall certainly be able to imagine the heavenly body which lies at the juncture of all the rims, as being carried forward in as erratic and wobbly a manner as could be desired. In other words, the theory of epicycles will account for all the facts of the observed motions of all the heavenly bodies, but in so doing it fills the universe with a most bewildering network of intersecting circles. Even in the time of Calippus fifty-five of these spheres were computed.

We may well believe that the clear-seeing Aristarchus would look askance at such a complex system of imaginary machinery. But Hipparchus, pre-eminently an observer rather than a theorizer, seems to have been content to accept the theory of epicycles as he found it, though his studies added to its complexities; and Hipparchus was the dominant scientific personality of his century. What he believed became as a law to his immediate successors. His tenets were accepted as final by their great popularizer, Ptolemy, three centuries later; and so the heliocentric theory of Aristarchus passed under a cloud almost at the hour of its dawning, there to remain obscured and forgotten for the long lapse of centuries. A thousand pities that the greatest observing astronomer of antiquity could not, like one of his great precursors, have approached astronomy from the stand-point of geography and poetry Had he done so, perhaps he might have reflected, like Aristarchus before him, that it seems absurd for our earth to hold the giant sun in thraldom; then perhaps his imagination would have reached out to the heliocentric doctrine, and the cobweb hypothesis of epicycles, with that yet more intangible figment of the perfect circle, might have been wiped away.

But it was not to be. With Aristarchus the scientific imagination had reached its highest flight; but with Hipparchus it was beginning to settle back into regions of foggier atmosphere and narrower horizons. For what, after all, does it matter that Hipparchus should go on to measure the precise length of the year and the apparent size of the moon's disk; that he should make a chart of the heavens showing the place of 1080 stars; even that he should discover the precession of the equinox;—what, after all, is the significance of these details as against the all-essential fact that the greatest scientific authority of his century—the one truly heroic scientific figure of his epoch—should have lent all the forces of his commanding influence to the old, false theory of cosmology, when the true theory had been propounded and when he, perhaps, was the only man in the world who might have substantiated and vitalized that theory? It is easy to overestimate the influence of any single man, and, contrariwise, to underestimate the power of the *Zeitgeist*. But when we reflect that the doctrines of Hipparchus, as promulgated by Ptolemy, became, as it were, the last word of astronomical science for both the Eastern and Western worlds, and so continued after a thousand years, it is perhaps not too much to say that Hipparchus, "the lover of truth," missed one of the greatest opportunities for the promulgation of truth ever vouchsafed to a devotee of pure science.

But all this, of course, detracts nothing from the merits of Hipparchus as an observing astronomer. A few words more must be said as to his specific discoveries in this field. According to his measurement, the tropic year consists of 365 days, 5 hours, and 49 minutes, varying thus only 12 seconds from the true year, as the modern astronomer estimates it. Yet more remarkable, because of the greater difficulties involved, was Hipparchus's attempt to measure the actual distance of the moon. Aristarchus had made a similar attempt before him. Hipparchus based his computations on studies of the moon in eclipse, and he reached the conclusion that the distance of the moon is equal to 59 radii of the earth (in reality it is 60.27 radii). Here, then, was the measure of the base-line of that famous triangle with which Aristarchus had measured the distance of the sun. Hipparchus must have known of that measurement, since he quotes the work of Aristarchus in other fields. Had he now but repeated the experiment of Aristarchus, with his perfected instruments and his perhaps greater observational skill, he was in position to compute the actual distance of the sun in terms not merely of the moon's distance but of the earth's radius. And now there was the experiment of Eratosthenes to give the length of that radius in precise terms. In other words, Hipparchus might have measured the distance of the sun in stadia. But if he had made the attempt—and, indeed, it is more than likely that he did so—the elements of error in his measurements would still have kept him wide of the true figures.

The chief studies of Hipparchus were directed, as we have seen, towards the sun and the moon, but a phenomenon that occurred in the year 134 B.C. led him for a time to give more particular attention to the fixed stars. The phenomenon in question was the sudden outburst of a new star; a phenomenon which has been repeated now and again, but which is sufficiently rare and sufficiently mysterious to have excited the unusual attention of astronomers in all generations. Modern science offers an explanation of the phenomenon, as we shall see in due course. We do not know that Hipparchus attempted to explain it, but he was led to make a chart of the heavens, probably with the idea of guiding future observers in the observation of new stars. Here again Hipparchus was not altogether an innovator, since a chart showing the brightest stars had been made by Eratosthenes; but the new charts were much elaborated.

The studies of Hipparchus led him to observe the stars chiefly with reference to the meridian rather than with reference to their rising, as had hitherto been the custom. In making these studies of the relative position of the stars, Hipparchus was led to compare his observations with those of the Babylonians, which, it was said, Alexander had caused to be transmitted to Greece. He made use also of the observations of Aristarchus and others of his Greek precursors. The result of his comparisons proved that the sphere of the fixed stars had apparently shifted its position in reference to the plane of the sun's orbit—that is to say, the plane of the ecliptic no longer seemed to cut the sphere of the fixed stars at precisely the point where the two coincided in former centuries. The plane of the ecliptic must therefore be conceived as slowly revolving in such a way as gradually to circumnavigate the heavens. This important phenomenon is described as the precession of the equinoxes.

It is much in question whether this phenomenon was not known to the ancient Egyptian astronomers; but in any event, Hipparchus is to be credited with demonstrating the fact and making it known to the Western world. A further service was rendered theoretical astronomy by Hipparchus through his invention of the planosphere, an instrument for the representation of the mechanism of the heavens. His computations of the properties of the spheres led him also to what was virtually a discovery of the method of trigonometry, giving him, therefore, a high position in the field of mathematics. All in all, then, Hipparchus is a most heroic figure. He may well be considered the greatest star-gazer of antiquity, though he cannot, without injustice to his great precursors, be allowed the title which is sometimes given him of "father of systematic astronomy."

CTESIBIUS AND HERO: MAGICIANS OF ALEXANDRIA

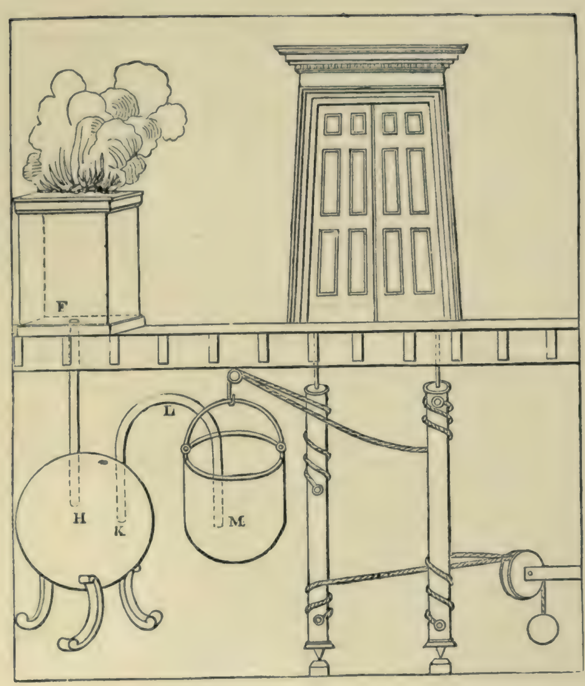
Just about the time when Hipparchus was working out at Rhodes his puzzles of celestial mechanics, there was a man in Alexandria who was exercising a strangely inventive genius over mechanical problems of another sort; a man who, following the example set by Archimedes a century before, was studying the problems of matter and putting his studies to practical application through the invention of weird devices The man's name was Ctesibius. We know scarcely more of him than that he lived in Alexandria, probably in the first half of the second century B.C. His antecedents, the place and exact time of his birth and death, are quite unknown. Neither are we quite certain as to the precise range of his studies or the exact number of his discoveries. It appears that he had a pupil named Hero, whose personality, unfortunately, is scarcely less obscure than that of his master, but who wrote a book through which the record of the master's inventions was preserved to posterity. Hero, indeed, wrote several books, though only one of them has been preserved. The ones that are lost bear the following suggestive titles: *On the Construction of Slings; On the Construction of Missiles; On the Automaton; On the Method of Lifting Heavy Bodies; On the Dioptric or Spying-tube.* The work that remains is called *Pneumatics*, and so interesting a work it is as to make us doubly regret the loss of its companion volumes. Had these other books been preserved we should doubtless have a clearer insight than is now possible into some at least of the mechanical problems that exercised the minds of the ancient philosophers. The book that remains is chiefly concerned, as its name implies, with the study of gases, or, rather, with the study of a single gas, this being, of course, the air. But it tells us also of certain studies in the dynamics of water that are most interesting, and for the historian of science most important.

Unfortunately, the pupil of Ctesibius, whatever his ingenuity, was a man with a deficient sense of the ethics of science. He tells us in his preface that the object of his book is to record some ingenious discoveries of others, together with additional discoveries of his own, but nowhere in the book itself does he give us the slightest clew as to where the line is drawn between the old and the new. Once, in discussing the weight of water, he mentions the law of Archimedes regarding a floating body, but this is the only case in which a scientific principle is traced to its source or in which credit is given to any one for a discovery. This is the more to be regretted because Hero has discussed at some length the theories involved in the treatment of his subject. This reticence on the part of Hero, combined with the fact that such somewhat later writers as Pliny and Vitruvius do not mention Hero's name, while they frequently mention the name of his master, Ctesibius, has led modern critics to a somewhat sceptical attitude regarding the position of Hero as an actual discoverer.

The man who would coolly appropriate some discoveries of others under cloak of a mere prefatorial reference was perhaps an expounder rather than an innovator, and had, it is shrewdly suspected, not much of his own to offer. Meanwhile, it is tolerably certain that Ctesibius was the discoverer of the principle of the siphon, of the forcing-pump, and of a pneumatic organ. An examination of Hero's book will show that these are really the chief principles involved in most of the various interesting mechanisms which he describes. We are constrained, then, to believe that the inventive genius who was really responsible for the mechanisms we are about to describe was Ctesibius, the master. Yet we owe a debt of gratitude to Hero, the pupil, for having given wider vogue to these discoveries, and in particular for the discussion of the principles of hydrostatics and pneumatics contained in the introduction to his book. This discussion furnishes us almost our only knowledge as to the progress of Greek philosophers in the field of mechanics since the time of Archimedes.

The main purpose of Hero in his preliminary thesis has to do with the nature of matter, and recalls, therefore, the studies of Anaxagoras and Democritus. Hero, however, approaches his subject from a purely material or practical stand-point. He is an explicit champion of what we nowadays call the molecular theory of matter. "Every body," he tells us, "is composed of minute particles, between which are empty spaces less than these particles of the body. It is, therefore, erroneous to say that there is no vacuum except by the application of force, and that every space is full either of air or water or some other substance. But in proportion as any one of these particles recedes, some other follows it and fills the vacant space; therefore there is no continuous vacuum, except by the application of some force [like suction]—that is to say, an absolute vacuum is never found, except as it is produced artificially." Hero brings forward some thoroughly convincing proofs of the thesis he is maintaining. "If there were no void places between the particles of water," he says, "the rays of light could not penetrate the water; moreover, another liquid, such as wine, could not spread itself through the water, as it is observed to do, were the particles of water absolutely continuous." The latter illustration is one the validity of which appeals as forcibly to the physicists of to-day as it did to Hero. The same is true of the argument drawn from the compressibility of gases. Hero has evidently made a careful study of this subject He knows that an inverted tube full of air may be immersed in water without becoming wet on the inside, proving that air is a physical substance; but he knows also that this same air may be caused to expand to a much greater bulk by the application of heat, or may, on the other hand, be condensed by pressure, in which case, as he is well aware, the air exerts force in the attempt to regain its normal bulk. But, he argues, surely we are not to believe that the particles of air expand to fill all the space when the bulk of air as a whole expands under the influence of heat; nor can we conceive that the particles of normal air are in actual contact, else we should not be able to compress the air. Hence his conclusion, which, as we have seen, he makes general in its application to all matter, that there are spaces, or, as he calls them, vacua, between the particles that go to make up all substances, whether liquid, solid, or gaseous.

Here, clearly enough, was the idea of the "atomic" nature of matter accepted as a fundamental notion. The argumentative attitude assumed by Hero shows that the doctrine could not be expected to go unchallenged. But, on the other hand, there is nothing in his phrasing to suggest an intention to claim originality for any phase of the doctrine. We may infer that in the three hundred years that had elapsed since



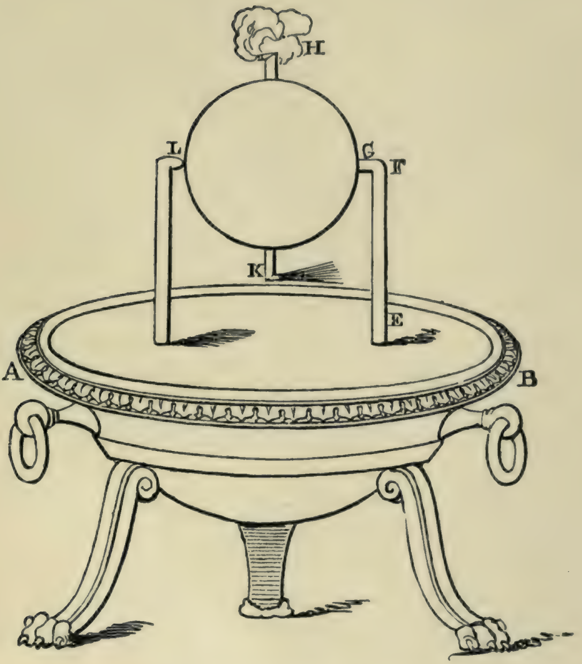
DEVICE FOR CAUSING THE DOORS OF THE TEMPLE TO OPEN WHEN THE FIRE ON THE ALTAR IS LIGHTED

(Air heated in the altar F drives water from the closed receptacle H through the tube KL into the bucket M, which descends through gravity, thus opening the doors. When the altar cools, the air contracts, the water is sucked from the bucket, and the weight and pulley close the doors. See p. 248.)

the time of Anaxagoras, that philosopher's idea of the molecular nature of matter had gained fairly wide currency. As to the expansive power of gas, which Hero describes at some length without giving us a clew to his authorities, we may assume that Ctesibius was an original worker, yet the general facts involved were doubtless much older than his day. Hero, for example, tells us of the cupping-glass used by physicians, which he says is made into a vacuum by burning up the air in it; but this apparatus had probably been long in use, and Hero mentions it not in order to describe the ordinary cupping-glass which is referred to, but a modification of it. He refers to the old form as if it were something familiar to all.

Again, we know that Empedocles studied the pressure of the air in the fifth century B.C., and discovered that it would support a column of water in a closed tube, so this phase of the subject is not new. But there is no hint anywhere before this work of Hero of a clear understanding that the expansive properties of the air when compressed, or when heated, may be made available as a motor power. Hero, however, has the clearest notions on the subject and puts them to the practical test of experiment. Thus he constructs numerous mechanisms in which the expansive power of air under pressure is made to do work, and others in which the same end is accomplished through the expansive power of heated air. For example, the doors of a temple are made to swing open automatically when a fire is lighted on a distant altar, closing again when the fire dies out—effects which must have filled the minds of the pious observers with bewilderment and wonder, serving a most useful purpose for the priests, who alone, we may assume, were in the secret. There were two methods by which this apparatus was worked. In one the heated air pressed on the water in a close retort connected with the altar, forcing water out of the retort into a bucket, which by its weight applied a force through pulleys and ropes that turned the standards on which the temple doors revolved. When the fire died down the air contracted, the water was siphoned back from the bucket, which, being thus lightened, let the doors close again through the action of an ordinary weight. The other method was a slight modification, in which the retort of water was dispensed with and a leather sack like a large football substitued. The ropes and pulleys were connected with this sack, which exerted a pull when the hot air expanded, and which collapsed and thus relaxed its strain when the air cooled. A glance at the illustrations taken from Hero's book will make the details clear.

Other mechanisms utilized a somewhat different combination of weights, pulleys, and siphons, operated by the expansive power of air, unheated but under pressure, such pressure being applied with a force-pump, or by the weight of water running into a closed receptacle. One such mechanism gives us a constant jet of water or perpetual fountain. Another curious application of the principle furnishes us with an elaborate toy, consisting of a group of birds which alternately whistle or are silent, while an owl seated on a neighboring perch turns towards the birds when their song begins and away from them when it ends. The "singing" of the birds, it must be explained, is pro-



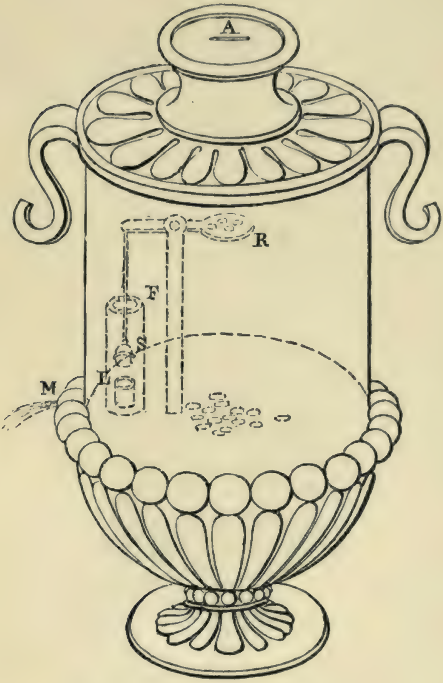
THE STEAM-ENGINE OF HERO

(The steam generated in the receptacle AB passes through the tube EF into the globe, and escapes through the bent tubes H and K, causing the globe to rotate on the axis LG. See p. 250.)

duced by the expulsion of air through tiny tubes passing up through their throats from a tank below. The owl is made to turn by a mechanism similar to that which manipulates the temple doors. The pressure is supplied merely by a stream of running water, and the periodical silence of the birds is due to the fact that this pressure is relieved through the automatic siphoning off of the water when it reaches a certain height. The action of the siphon, it may be added, is correctly explained by Hero as due to the greater weight of the water in the longer arm of the bent tube. As before mentioned, the siphon is repeatedly used in these mechanisms of Hero. The diagram will make clear the exact application of it in the present most ingenious mechanism. We may add that the principle of the whistle was a favorite one of Hero. By the aid of a similar mechanism he brought about the blowing of trumpets when the temple doors were opened, a phenomenon which must greatly have enhanced the mystification. It is possible that this principle was utilized also in connection with statues to produce seemingly supernatural effects. This may be the explanation of the tradition of the speaking statue in the temple of Ammon at Thebes.

The utilization of the properties of compressed air was not confined, however, exclusively to mere toys, or to produce miraculous effects. The same principle was applied to a practical fire-engine, worked by levers and force-pumps; an apparatus, in short, altogether similar to that still in use in rural districts. A slightly different application of the motive power of expanding air is furnished in a very curious toy called "the dancing figures." In this, air heated in a retort like a miniature altar is allowed to escape through the sides of two pairs of revolving arms precisely like those of the ordinary revolving fountain with which we are accustomed to water our lawns, the revolving arms being attached to a plane on which several pairs of statuettes representing dancers are placed. An even more interesting application of this principle of setting a wheel in motion is furnished in a mechanism which must be considered the earliest of steam-engines. Here, as the name implies, the gas supplying the motive power is actually steam. The apparatus made to revolve is a globe connected with the steam-retort by a tube which serves as one of its axes, the steam escaping from the globe through two bent tubes placed at either end of an equatorial diameter. It does not appear that Hero had any thought of making practical use of this steam-engine. It was merely a curious toy—nothing more. Yet had not the age that succeeded that of Hero been one in which inventive genius was dormant, some one must soon have hit upon the idea that this steam-engine might be improved and made to serve a useful purpose. As the case stands, however, there was no advance made upon the steam motor of Hero for almost two thousand years. And, indeed, when the practical application of steam was made, towards the close of the eighteenth century, it was made probably quite without reference to the experiment of Hero, though knowledge of his toy may perhaps have given a clew to Watt or his predecessors.

In recent times there has been a tendency to give to this steam-engine of Hero something more than



THE SLOT-MACHINE OF HERO

(The coin introduced at A falls on the lever R, and by its weight opens the valve S, permitting the liquid to escape through the invisible tube LM. As the lever tips, the coin slides off and the valve closes. The liquid in the tank must of course be kept above F. See p. 251.)

full meed of appreciation. To be sure, it marked a most important principle in the conception that steam might be used as a motive power, but, except in the demonstration of this principle, the mechanism of Hero was much too primitive to be of any importance. But there is one mechanism described by Hero which was a most explicit anticipation of a device, which presumably soon went out of use, and which was not reinvented until towards the close of the nineteenth century. This was a device which has become familiar in recent times as the penny-in-the-slot machine. When towards the close of the nineteenth century some inventive craftsman hit upon the idea of an automatic machine to supply candy, a box of cigarettes, or a whiff of perfumery, he may or may not have borrowed his idea from the slot-machine of Hero; but in any event, instead of being an innovator he was really two thousand years behind the times, for the slot-machine of Hero is the precise prototype of these modern ones.

The particular function which the mechanism of Hero was destined to fulfil was the distribution of a jet of water, presumably used for sacramental purposes, which was given out automatically when a five-drachma coin was dropped into the slot at the top of the machine. The internal mechanism of the machine was simple enough, consisting merely of a lever operating a valve which was opened by the weight of the coin dropping on the little shelf at the end of the lever, and which closed again when the coin slid off the shelf. The illustration will show how simple this mechanism was. Yet to the worshippers, who probably had entered the temple through doors miraculously opened, and who now witnessed this seemingly intelligent response of a machine, the result must have seemed mystifying enough; and, indeed, for us also, when we consider how relatively crude was the mechanical knowledge of the time, this must seem nothing less than marvellous. As in imagination we walk up to the sacred tank, drop our drachma in the slot, and hold our hand for the spurt of holy-water, can we realize that this is the land of the Pharaohs, not England or America; that the kingdom of the Ptolemies is still at its height; that the republic of Rome is mistress of the world; that all Europe north of the Alps is inhabited solely by barbarians; that Cleopatra and Julius Cæsar are yet unborn; that the Christian era has not yet begun? Truly, it seems as if there could be no new thing under the sun.

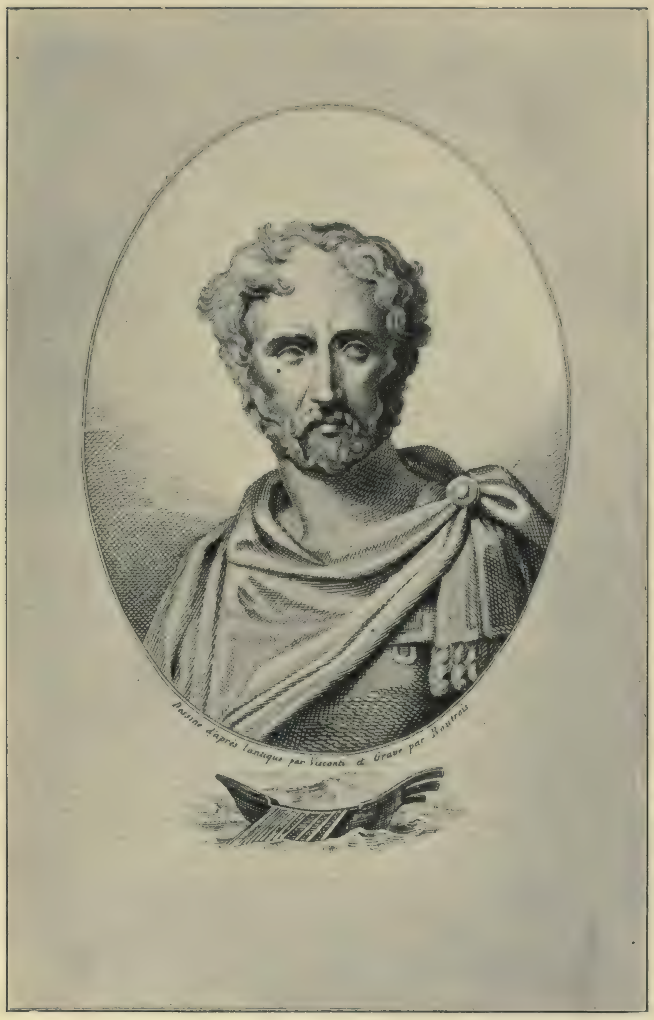
IX

SCIENCE OF THE ROMAN PERIOD

WE have seen that the third century B.C. was a time when Alexandrian science was at its height, but that the second century produced also in Hipparchus at least one investigator of the very first rank; though, to be sure, Hipparchus can be called an Alexandrian only by courtesy. In the ensuing generations the Greek capital at the mouth of the Nile continued to hold its place as the centre of scientific and philosophical thought. The kingdom of the Ptolemies still flourished with at least the outward appearances of its old-time glory, and a company of grammarians and commentators of no small merit could always be found in the service of the famous museum and library; but the whole aspect of world-history was rapidly changing. Greece, after her brief day of political supremacy, was sinking rapidily into desuetude, and the hard-headed Roman in the West was making himself master everywhere. While Hipparchus of Rhodes was in his prime, Corinth, the last stronghold of the main-land of Greece, had fallen before the prowess of the Roman, and the kingdom of the Ptolemies, though still nominally free, had begun to come within the sphere of Roman influence.

Just what share these political changes had in changing the aspect of Greek thought is a question regarding which difference of opinion might easily prevail; but there can be no question that, for one reason or another, the Alexandrian school as a creative centre went into a rapid decline at about the time of the Roman rise to world-power. There are some distinguished names, but, as a general rule, the spirit of the times is reminiscent rather than creative; the workers tend to collate the researches of their predecessors rather than to make new and original researches for themselves. Eratosthenes, the inventive world-measurer, was succeeded by Strabo, the industrious collator of facts; Aristarchus and Hipparchus, the originators of new astronomical methods, were succeeded by Ptolemy, the perfecter of their methods and the systematizer of their knowledge. Meanwhile, in the West, Rome never became a true culture-centre. The great genius of the Roman was political; the Augustan Age produced a few great historians and poets, but not a single great philosopher or creative devotee of science. Cicero, Lucian, Seneca, Marcus Aurelius, give us at best a reflection of Greek philosophy. Pliny, the one world-famous name in the scientific annals of Rome, can lay claim to no higher credit than that of a marvellously industrious collector of facts—the compiler of an encyclopædia which contains not one creative touch.

All in all, then, this epoch of Roman domination is one that need detain the historian of science but a brief moment. With the culmination of Greek effort in the so-called Hellenistic period we have seen ancient science at its climax. The Roman period is but a time of transition, marking, as it were, a plateau on the slope between those earlier heights and the deep,


Dessiné d'après l'antique par Visconti et Gravé par Boutrois

PLINY

(From an old print.)

dark valleys of the Middle Ages. Yet we cannot quite disregard the efforts of such workers as those we have just named. Let us take a more specific glance at their accomplishments.

STRABO THE GEOGRAPHER

The earliest of these workers in point of time is Strabo. This most famous of ancient geographers was born in Amasia, Pontus, about 63 B.C., and lived to the year 24 A.D., living, therefore, in the age of Cæsar and Augustus, during which the final transformation in the political position of the kingdom of Egypt was effected. The name of Strabo in a modified form has become popularized through a curious circumstance. The geographer, it appears, was afflicted with a peculiar squint of the eyes, hence the name strabismus, which the modern oculist applies to that particular infirmity.

Fortunately, the great geographer has not been forced to depend upon hearsay evidence for recognition. His comprehensive work on geography has been preserved in its entirety, being one of the few expansive classical writings of which this is true. The other writings of Strabo, however, including certain histories of which reports have come down to us, are entirely lost. The geography is in many ways a remarkable book. It is not, however, a work in which any important new principles are involved. Rather is it typical of its age in that it is an elaborate compilation and a critical review of the labors of Strabo's predecessors. Doubtless it contains a vast deal of new information as to the details of geography—precise areas and distance, questions of geographical locations as to latitude and zones, and the like. But however important these details may have been from a contemporary stand-point, they, of course, can have nothing more than historical interest to posterity. The value of the work from our present stand-point is chiefly due to the criticisms which Strabo passes upon his forerunners, and to the incidental historical and scientific references with which his work abounds. Being written in this closing period of ancient progress, and summarizing, as it does, in full detail the geographical knowledge of the time, it serves as an important guide-mark for the student of the progress of scientific thought. We cannot do better than briefly to follow Strabo in his estimates and criticisms of the work of his predecessors, taking note thus of the point of view from which he himself looked out upon the world. We shall thus gain a clear idea as to the state of scientific geography towards the close of the classical epoch.

"If the scientific investigation of any subject be the proper avocation of the philosopher," says Strabo, "geography, the science of which we propose to treat, is certainly entitled to a high place; and this is evident from many considerations. They who first undertook to handle the matter were distinguished men. Homer, Anaximander the Milesian, and Hecatæus (his fellow-citizen according to Eratosthenes), Democritus, Eudoxus, Dicæarchus, and Ephorus, with many others, and after these, Eratosthenes, Polybius, and Posidonius, all of them philosophers. Nor is the great learning through which alone this subject can be approached possessed by any but a person acquainted with both human and divine things, and these attainments constitute what is called philosophy. In addition to its vast importance in regard to social life and the art of government, geography unfolds to us a celestial phenomena, acquaints us with the occupants of the land and ocean, and the vegetation, fruits, and peculiarities of the various quarters of the earth, a knowledge of which marks him who cultivates it as a man earnest in the great problem of life and happiness."

Strabo goes on to say that in common with other critics, including Hipparchus, he regards Homer as the first great geographer. He has much to say on the geographical knowledge of the bard, but this need not detain us. We are chiefly concerned with his comment upon his more recent predecessors, beginning with Eratosthenes. The constant reference to this worker shows the important position which he held. Strabo appears neither as detractor nor as partisan, but as one who earnestly desires the truth. Sometimes he seems captious in his criticisms regarding some detail, nor is he always correct in his emendations of the labors of others; but, on the whole, his work is marked by an evident attempt at fairness. In reading his book, however, one is forced to the conclusion that Strabo is an investigator of details, not an original thinker. He seems more concerned with precise measurements than with questionings as to the open problems of his science. Whatever he accepts, then, may be taken as virtually the stock doctrine of the period.

"As the size of the earth," he says, "has been demonstrated by other writers, we shall here take for granted and receive as accurate what they have advanced. We shall also assume that the earth is spheroidal, that its surface is likewise spheroidal and, above all, that bodies have a tendency towards its centre, which latter point is clear to the perception of the most average understanding. However, we may show summarily that the earth is spheroidal, from the consideration that all things, however distant, tend to its centre, and that every body is attracted towards its centre by gravity. This is more distinctly proved from observations of the sea and sky, for here the evidence of the senses and common observation is alone requisite. The convexity of the sea is a further proof of this to those who have sailed, for they cannot perceive lights at a distance when placed at the same level as their eyes, and if raised on high they at once become perceptible to vision though at the same time farther removed. So when the eye is raised it sees what before was utterly imperceptible. Homer speaks of this when he says:

> " 'Lifted up on the vast wave he quickly beheld afar.'

Sailors as they approach their destination behold the shore continually raising itself to their view, and objects which had at first seemed low begin to lift themselves. Our gnomons, also, are, among other things, evidence of the revolution of the heavenly bodies, and common-sense at once shows us that if the depth of the earth were infinite such a revolution could not take place."[1]

Elsewhere Strabo criticises Eratosthenes for having entered into a long discussion as to the form of the earth. This matter, Strabo thinks, "should have been disposed of in the compass of a few words." Obviously this doctrine of the globe's sphericity had, in the course of 600 years, become so firmly established among the Greek thinkers as to seem almost axiomatic. We shall see later on how the Western world made a curious recession from this seemingly secure position under stimulus of an Oriental misconception. As to the size of the globe, Strabo is disposed to accept without particular comment the measurements of Eratosthenes. He speaks, however, of "more recent measurements," referring in particular to that adopted by Posidonius, according to which the circumference is only about one hundred and eighty thousand stadia. Posidonius, we may note in passing, was a contemporary and friend of Cicero, and hence lived shortly before the time of Strabo. His measurement of the earth was based on observations of a star which barely rose above the southern horizon at Rhodes as compared with the height of the same star when observed at Alexandria. This measurement of Posidonius, together with the even more famous measurement of Eratosthenes, appears to have been practically the sole guide as to the size of the earth throughout the later periods of antiquity, and, indeed, until the later Middle Ages.

As becomes a writer who is primarily geographer and historian rather than astronomer, Strabo shows a much keener interest in the habitable portions of the globe than in the globe as a whole. He assures us that this habitable portion of the earth is a great island, "since wherever men have approached the termination of the land, the sea, which we designate ocean, has been met with, and reason assures us of the similarity of this place which our senses have not been tempted to survey." He points out that whereas sailors have not circumnavigated the globe, that they had not been prevented from doing so by any continent, and it seems to him altogether unlikely that the Atlantic Ocean is divided into two seas by narrow isthmuses so placed as to prevent circumnavigation. "How much more probable that it is confluent and uninterrupted. This theory," he adds, "goes better with the ebb and flow of the ocean. Moreover (and here his reasoning becomes more fanciful), the greater the amount of moisture surrounding the earth, the easier would the heavenly bodies be supplied with vapor from thence." Yet he is disposed to believe, following Plato, that the tradition "concerning the island of Atlantos might be received as something more than idle fiction, it having been related by Solon, on the authority of the Egyptian priests, that this island, almost as large as a continent, was formerly in existence although now it had disappeared."[2]

In a word, then, Strabo entertains no doubt whatever that it would be possible to sail around the globe from Spain to India. Indeed, so matter-of-fact an inference was this that the feat of Columbus would have seemed less surprising in the first century of our era than it did when actually performed in the fifteenth century. The terrors of the great ocean held the mariner back, rather than any doubt as to where he would arrive at the end of the voyage.

Coupled with the idea that the habitable portion of the earth is an island, there was linked a tolerably definite notion as to the shape of this island. This shape Strabo likens to a military cloak. The comparison does not seem peculiarly apt when we are told presently that the length of the habitable earth is more than twice its breadth. This idea, Strabo assures us, accords with the most accurate observations "both ancient and modern." These observations seemed to show that it is not possible to live in the region close to the equator, and that, on the other hand, the cold temperature sharply limits the habitability of the globe towards the north. All the civilization of antiquity clustered about the Mediterranean, or extended off towards the east at about the same latitude. Hence geographers came to think of the habitable globe as having the somewhat lenticular shape which a crude map of these regions suggests. We have already had occasion to see that at an earlier day Anaxagoras was perhaps influenced in his conception of the shape of the earth by this idea, and the constant references of Strabo impress upon us the thought that this long, relatively narrow area of the earth's surface is the only one which can be conceived of as habitable.

Strabo had much to tell us concerning zones, which, following Posidonius, he believes to have been first described by Parmenides. We may note, however, that other traditions assert that both Thales and Pythagoras had divided the earth into zones. The number of zones accepted by Strabo is five, and he criticises Polybius for making the number six. The five zones accepted by Strabo are as follows: the uninhabitable torrid zone lying in the region of the equator; a zone on either side of this extending to the tropic; and then the temperate zones extending in either direction from the tropic to the arctic regions. There seems to have been a good deal of dispute among the scholars of the time as to the exact arrangement of these zones, but the general idea that the north-temperate zone is the part of the earth with which the geographer deals seemed clearly established. That the south-temperate zone would also present a habitable area is an idea that is sometimes suggested, though seldom or never distinctly expressed. It is probable that different opinions were held as to this, and no direct evidence being available, a cautiously scientific geographer like Strabo would naturally avoid the expression of an opinion regarding it. Indeed, his own words leave us somewhat in doubt as to the precise character of his notion regarding the zones. Perhaps we shall do best to quote them:

"Let the earth be supposed to consist of five zones. (1) The equatorial circle described around it. (2) Another parallel to this, and defining the frigid zone of the northern hemisphere. (3) A circle passing through the poles and cutting the two preceding circles at right-angles. The northern hemisphere contains two quarters of the earth, which are bounded by the equator and circle passing through the poles. Each of these quarters should be supposed to contain a four-sided district, its northern side being of one-half of the parallel next the pole, its southern by the half of the equator, and its remaining sides by two segments of the circle drawn through the poles, opposite to each other, and equal in length. In one of these (which of them is of no consequence) the earth which we inhabit is situated, surrounded by a sea and similar to an island. This, as we said before, is evident both to our senses and to our reason. But let any one doubt this, it makes no difference so far as geography is concerned whether you believe the portion of the earth which we inhabit to be an island or only admit what we know from experience —namely, that whether you start from the east or the west you may sail all around it. Certain intermediate spaces may have been left (unexplored), but these are as likely to be occupied by sea as uninhabited land. The object of the geographer is to describe known countries. Those which are unknown he passes over equally with those beyond the limits of the inhabited earth. It will, therefore, be sufficient for describing the contour of the island we have been speaking of, if we join by a right line the outmost points which, up to this time, have been explored by voyagers along the coast on either side." [3]

We may pass over the specific criticisms of Strabo upon various explorations that seem to have been of great interest to his contemporaries, including an alleged trip of one Eudoxus out into the Atlantic, and the journeyings of Pytheas in the far north. It is Pytheas, we may add, who was cited by Hipparchus as having made the mistaken observation that the length of the shadow of the gnomon is the same at Marseilles and Byzantium, hence that these two places are on the same parallel. Modern commentators have defended Pytheas as regards this observation, claiming that it was Hipparchus and not Pytheas who made the second observation from which the faulty induction was drawn. The point is of no great significance, however, except as showing that a correct method of determining the problems of latitude had thus early been suggested. That faulty observations and faulty application of the correct principle should have been made is not surprising. Neither need we concern ourselves with the details as to the geographical distances, which Strabo found so worthy of criticism and controversy. But in leaving the great geographer we may emphasize his point of view and that of his contemporaries by quoting three fundamental principles which he reiterates as being among the "facts established by natural philosophers." He tells us that "(1) The earth and heavens are spheroidal. (2) The tendency of all bodies having weight is towards a centre. (3) Further, the earth being spheroidal and having the same centre as the heavens, is motionless, as well as the axis that passes through both it and the heavens. The heavens turn round both the earth and its axis, from east to west. The fixed stars turn round with it at the same rate as the whole. These fixed stars follow in their course parallel circles, the principal of which are the equator, two tropics, and the arctic circles; while the planets, the sun, and the moon describe certain circles comprehended within the zodiac."[4]

Here, then, is a curious mingling of truth and error. The Pythagorean doctrine that the earth is round had become a commonplace, but it would appear that the theory of Aristarchus, according to which the earth is in motion, has been almost absolutely forgotten. Strabo does not so much as refer to it; neither, as we shall see, is it treated with greater respect by the other writers of the period.

TWO FAMOUS EXPOSITORS—PLINY AND PTOLEMY

While Strabo was pursuing his geographical studies at Alexandria, a young man came to Rome who was destined to make his name more widely known in scientific annals than that of any other Latin writer of antiquity. This man was Plinius Secundus, who, to distinguish him from his nephew, a famous writer in another field, is usually spoken of as Pliny the Elder. There is a famous story to the effect that the great Roman historian Livy on one occasion addressed a casual associate in the amphitheatre at Rome, and on learning that the stranger hailed from the outlying Spanish province of the empire, remarked to him, "Yet you have doubtless heard of my writings even there." "Then," replied the stranger, "you must be either Livy or Pliny."

The anecdote illustrates the wide fame which the Roman naturalist achieved in his own day. And the records of the Middle Ages show that this popularity did not abate in succeeding times. Indeed, the *Natural History* of Pliny is one of the comparatively few bulky writings of antiquity that the efforts of copyists have preserved to us almost entire. It is, indeed, a remarkable work and eminently typical of its time; but its author was an industrious compiler, not a creative genius. As a monument of industry it has seldom been equalled, and in this regard it seems the more remarkable inasmuch as Pliny was a practical man of affairs who occupied most of his life as a soldier fighting the battles of the empire. He compiled his book in the leisure hours stolen from sleep, often writing by the light of the camp-fire. Yet he cites or quotes from about four thousand works, most of which are known to us only by his references. Doubtless Pliny added much through his own observations. We know how keen was his desire to investigate, since he lost his life through attempting to approach the crater of Vesuvius on the occasion of that memorable eruption which buried the cities of Herculaneum and Pompeii.

Doubtless the wandering life of the soldier had given Pliny abundant opportunity for personal observation in his favorite fields of botany and zoology. But the records of his own observations are so intermingled with knowledge drawn from books that it is difficult to distinguish the one from the other. Nor does this greatly matter, for whether as closet-student or field-naturalist, Pliny's trait of mind is essentially that of the compiler. He was no philosophical thinker, no generalizer, no path-maker in science. He lived at the close of a great progressive epoch of thought; in one of those static periods when numberless observers piled up an immense mass of details which might advantageously be sorted into a kind of encyclopædia. Such an encyclopædia is the so-called *Natural History* of Pliny. It is a vast jumble of more or less uncritical statements regarding almost every field of contemporary knowledge. The descriptions of animals and plants predominate, but the work as a whole would have been immensely improved had the compiler shown a more critical spirit. As it is, he seems rather disposed to quote any interesting citation that he comes across in his omnivorous readings, shielding himself behind an equivocal "it is said," or "so and so alleges." A single illustration will suffice to show what manner of thing is thought worthy of repetition.

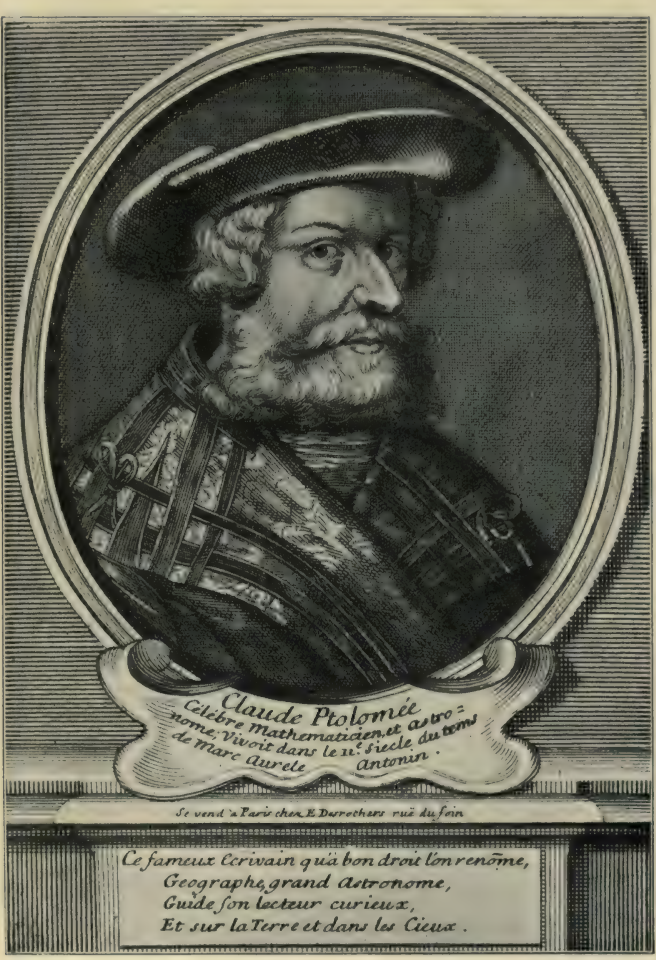
"It is asserted," he says, "that if the fish called a sea-star is smeared with the fox's blood and then nailed to the upper lintel of the door, or to the door itself, with a copper nail, no noxious spell will be able to obtain admittance, or, at all events, be productive of any ill effects."

It is easily comprehensible that a work fortified with such practical details as this should have gained wide popularity. Doubtless the natural histories of our own day would find readier sale were they to pander to various superstitions not altogether different from that here suggested. The man, for example, who believes that to have a black cat cross his path is a lucky omen would naturally find himself attracted by a book which took account of this and similar important details of natural history. Perhaps, therefore, it was its inclusion of absurdities, quite as much as its legitimate value, that gave vogue to the celebrated work of Pliny. But be that as it may, the most famous scientist of Rome must be remembered as a popular writer rather than as an experimental worker. In the history of the promulgation of scientific knowledge his work is important; in the history of scientific principles it may virtually be disregarded.

PTOLEMY, THE LAST GREAT ASTRONOMER OF ANTIQUITY

Almost the same thing may be said of Ptolemy, an even more celebrated writer, who was born not very long after the death of Pliny. The exact dates of Ptolemy's life are not known, but his recorded observations extend to the year 151 A.D. He was a working astronomer, and he made at least one original discovery of some significance—namely, the observation of a hitherto unrecorded irregularity of the moon's motion, which came to be spoken of as the moon's evection. This consists of periodical aberrations from the moon's regular motion in its orbit, which, as we now know, are due to the gravitation pull of the sun, but which remained unexplained until the time of Newton. Ptolemy also made original observations as to the motions of the planets. He is, therefore, entitled to a respectable place as an observing astronomer; but his chief fame rests on his writings.

His great works have to do with geography and astronomy. In the former field he makes an advance upon Strabo, citing the latitude of no fewer than five thousand places. In the field of astronomy, his great service was to have made known to the world the labors of Hipparchus. Ptolemy has been accused of taking the star-chart of his great predecessor without due credit, and indeed it seems difficult to clear him of this charge. Yet it is at least open to doubt whether he intended any impropriety, inasmuch as he all along is sedulous in his references to his predecessor. Indeed, his work might almost be called an exposition of the astronomical doctrines of Hipparchus. No one pretends that Ptolemy is to be compared with the Rhodesian observer as an original investigator, but as a popular expounder his superiority is evidenced in the fact that the writings of Ptolemy became practically


Claude Ptolomée
Célébre Mathematicien, et astro=
nome; Vivoit dans le 11.e Siecle du tems
de Marc aurele Antonin .
Se vend à Paris chez E Desrochers ruë du ſoin
Ce fameux Ecrivain qu'à bon droit l'on renōme,
Geographe, grand Astronome,
Guide ſon lecteur curieux,
Et sur la Terre et dans les Cieux .

PTOLEMY

(From an old print.)

the sole astronomical text-book of the Middle Ages both in the East and in the West, while the writings of Hipparchus were allowed to perish.

The most noted of all the writings of Ptolemy is the work which became famous under the Arabic name of *Almagest*. This word is curiously derived from the Greek title ἡ μεγίστη σύνταξις, "the greatest construction," a name given the book to distinguish it from a work on astrology in four books by the same author. For convenience of reference it came to be spoken of merely as ἡ μεγίστη, from which the Arabs form the title *Tabair al Magisthi*, under which title the book was published in the year 827. From this it derived the word *Almagest*, by which Ptolemy's work continued to be known among the Arabs, and subsequently among Europeans when the book again became known in the West. Ptolemy's book, as has been said, is virtually an elaboration of the doctrines of Hipparchus. It assumes that the earth is the fixed centre of the solar system, and that the stars and planets revolve about it in twenty-four hours, the earth being, of course, spherical. It was not to be expected that Ptolemy should have adopted the heliocentric idea of Aristarchus. Yet it is much to be regretted that he failed to do so, since the deference which was accorded his authority throughout the Middle Ages would doubtless have been extended in some measure at least to this theory as well, had he championed it. Contrariwise, his unqualified acceptance of the geocentric doctrine sufficed to place that doctrine beyond the range of challenge.

The *Almagest* treats of all manner of astronomical problems, but the feature of it which gained it widest celebrity was perhaps that which has to do with eccentrics and epicycles. This theory was, of course, but an elaboration of the ideas of Hipparchus; but, owing to the celebrity of the expositor, it has come to be spoken of as the theory of Ptolemy. We have sufficiently detailed the theory in speaking of Hipparchus. It should be explained, however, that, with both Hipparchus and Ptolemy, the theory of epicycles would appear to have been held rather as a working hypothesis than as a certainty, so far as the actuality of the minor spheres or epicycles is concerned. That is to say, these astronomers probably did not conceive either the epicycles or the greater spheres as constituting actual solid substances. Subsequent generations, however, put this interpretation upon the theory, conceiving the various spheres as actual crystalline bodies. It is difficult to imagine just how the various epicycles were supposed to revolve without interfering with the major spheres, but perhaps this is no greater difficulty than is presented by the alleged properties of the ether, which physicists of to-day accept as at least a working hypothesis. We shall see later on how firmly the conception of concentric crystalline spheres was held to, and that no real challenge was ever given that theory until the discovery was made that comets have an orbit that must necessarily intersect the spheres of the various planets.

Ptolemy's system of geography in eight books, founded on that of Marinus of Tyre, was scarcely less celebrated throughout the Middle Ages than the *Almagest*. It contained little, however, that need concern us here, being rather an elaboration of the doctrines to which we have already sufficiently referred. None of Ptolemy's original manuscripts has come down to us, but there is an alleged fifth-century manuscript attributed to Agathadamon of Alexandria which has peculiar interest because it contains a series of twenty-seven elaborately colored maps that are supposed to be derived from maps drawn up by Ptolemy himself. In these maps the sea is colored green, the mountains red or dark yellow, and the land white. Ptolemy assumed that a degree at the equator was 500 stadia instead of 604 stadia in length. We are not informed as to the grounds on which this assumption was made, but it has been suggested that the error was at least partially instrumental in leading to one very curious result. "Taking the parallel of Rhodes," says Donaldson,[5] "he calculated the longitudes from the Fortunate Islands to Cattigara or the west coast of Borneo at 180°, conceiving this to be one-half the circumference of the globe. The real distance is only 125° or 127°, so that his measurement is wrong by one-third of the whole, one-sixth for the error in the measurement of a degree and one-sixth for the errors in measuring the distance geometrically. These errors, owing to the authority attributed to the geography of Ptolemy in the Middle Ages, produced a consequence of the greatest importance. They really led to the discovery of America. For the design of Columbus to sail from the west of Europe to the east of Asia was founded on the supposition that the distance was less by one-third than it really was." This view is perhaps a trifle fanciful, since there is nothing to suggest that the courage of Columbus would have balked at the greater distance, and since the protests of the sailors, which nearly thwarted his efforts, were made long before the distance as estimated by Ptolemy had been covered; nevertheless it is interesting to recall that the great geographical doctrines, upon which Columbus must chiefly have based his arguments, had been before the world in an authoritative form practically unheeded for more than twelve hundred years, awaiting a champion with courage enough to put them to the test.

GALEN—THE LAST GREAT ALEXANDRIAN

There is one other field of scientific investigation to which we must give brief attention before leaving the antique world. This is the field of physiology and medicine. In considering it we shall have to do with the very last great scientist of the Alexandrian school. This was Claudius Galenus, commonly known as Galen, a man whose fame was destined to eclipse that of all other physicians of antiquity except Hippocrates, and whose doctrines were to have the same force in their field throughout the Middle Ages that the doctrines of Aristotle had for physical science. But before we take up Galen's specific labors, it will be well to inquire briefly as to the state of medical art and science in the Roman world at the time when the last great physician of antiquity came upon the scene.

The Romans, it would appear, had done little in the way of scientific discoveries in the field of medicine, but, nevertheless, with their practicality of mind, they had turned to better account many more of the scientific discoveries of the Greeks than did the discoverers themselves. The practising physicians in early Rome were mostly men of Greek origin, who came to the capital after the overthrow of the Greeks by the Romans. Many of them were slaves, as earning money by either bodily or mental labor was considered beneath the dignity of a Roman citizen. The wealthy Romans, who owned large estates and numerous slaves, were in the habit of purchasing some of these slave doctors, and thus saving medical fees by having them attend to the health of their families.

By the beginning of the Christian era medicine as a profession had sadly degenerated, and in place of a class of physicians who practised medicine along rational or legitimate lines, in the footsteps of the great Hippocrates, there appeared great numbers of "specialists," most of them charlatans, who pretended to possess supernatural insight in the methods of treating certain forms of disease. These physicians rightly earned the contempt of the better class of Romans, and were made the object of many attacks by the satirists of the time. Such specialists travelled about from place to place in much the same manner as the itinerant "Indian doctors" and "lightning tooth-extractors" do to-day. Eye-doctors seem to have been particularly numerous, and these were divided into two classes, eye-surgeons and eye-doctors proper. The eye-surgeon performed such operations as cauterizing for ingrowing eyelashes and operating upon growths about the eyes; while the eye-doctors depended entirely upon salves and lotions. These eye-salves were frequently stamped with the seal of the physician who compounded them, something like two hundred of these seals being still in existence. There were besides these quacks, however, reputable eye-doctors who must have possessed considerable skill in the treatment of certain ophthalmias. Among some Roman surgical instruments discovered at Rheims were found also some drugs employed by ophthalmic surgeons, and an analysis of these show that they contained, among other ingredients, some that are still employed in the treatment of certain affections of the eye.

One of the first steps taken in recognition of the services of physicians was by Julius Cæsar, who granted citizenship to all physicians practising in Rome. This was about fifty years before the Christian era, and from that time on there was a gradual improvement in the attitude of the Romans towards the members of the medical profession. As the Romans degenerated from a race of sturdy warriors and became more and more depraved physically, the necessity for physicians made itself more evident. Court physicians, and physicians-in-ordinary, were created by the emperors, as were also city and district physicians. In the year 133 A.D. Hadrian granted immunity from taxes and military service to physicians in recognition of their public services.

The city and district physicians, known as the *archiatri populaires*, treated and cared for the poor without remuneration, having a position and salary fixed by law and paid them semi-annually. These were honorable positions, and the *archiatri* were obliged to give instruction in medicine, without pay, to the poor students. They were allowed to receive fees and donations from their patients, but not, however, until the danger from the malady was past. Special laws were enacted to protect them, and any person subjecting them to an insult was liable to a fine "not exceeding one thousand pounds."

An example of Roman practicality is shown in the method of treating hemorrhage, as described by Aulus Cornelius Celsus (53 B.C. to 7 A.D.). Hippocrates and Hippocratic writers treated hemorrhage by application of cold, pressure, styptics, and sometimes by actual cauterizing; but they knew nothing of the simple method of stopping a hemorrhage by a ligature tied around the bleeding vessel. Celsus not only recommended tying the end of the injured vessel, but describes the method of applying two ligatures before the artery is divided by the surgeon—a common practice among surgeons at the present time. The cut is made between these two, and thus hemorrhage is avoided from either end of the divided vessel.

Another Roman surgeon, Heliodorus, not only describes the use of the ligature in stopping hemorrhage, but also the practice of torsion—twisting smaller vessels, which causes their lining membrane to contract in a manner that produces coagulation and stops hemorrhage. It is remarkable that so simple and practical a method as the use of the ligature in stopping hemorrhage could have gone out of use, once it had been discovered; but during the Middle Ages it was almost entirely lost sight of, and was not reintroduced until the time of Ambroise Paré, in the sixteenth century.

Even at a very early period the Romans recognized the advantage of surgical methods on the field of battle. Each soldier was supplied with bandages, and was probably instructed in applying them, something in the same manner as is done now in all modern armies. The Romans also made use of military hospitals and had established a rude but very practical field-ambulance service. "In every troop or bandon of two or four hundred men, eight or ten stout fellows were deputed to ride immediately behind the fighting-line to pick up and rescue the wounded, for which purpose their saddles had two stirrups on the left side, while they themselves were provided with water-flasks, and perhaps applied temporary bandages. They were encouraged by a reward of a piece of gold for each man they rescued. 'Noscomi' were male nurses attached to the military hospitals, but not inscribed 'on strength' of the legions, and were probably for the most part of the servile class."[6]

From the time of the early Alexandrians, Herophilus and Erasistratus, whose work we have already examined, there had been various anatomists of some importance in the Alexandrian school, though none quite equal to these earlier workers. The best-known names are those of Celsus (of whom we have already spoken), who continued the work of anatomical investigation, and Marinus, who lived during the reign of Nero, and Rufus of Ephesus. Probably all of these would have been better remembered by succeeding generations had their efforts not been eclipsed by those of Galen. This greatest of ancient anatomists was born at Pergamus of Greek parents. His father, Nicon, was an architect and a man of considerable ability. Until his fifteenth year the youthful Galen was instructed at home, chiefly by his father; but after that time he was placed under suitable teachers for instruction in the philosophical systems in vogue at that period. Shortly after this, however, the superstitious Nicon, following the interpretations of a dream, decided that his son should take up the study of medicine, and placed him under the instruction of several learned physicians.

Galen was a tireless worker, making long tours into Asia Minor and Palestine to improve himself in pharmacology, and studying anatomy for some time at Alexandria. He appears to have been full of the superstitions of the age, however, and early in his career made an extended tour into western Asia in search of the chimerical "jet-stone"—a stone possessing the peculiar qualities of "burning with a bituminous odor and supposed to possess great potency in curing such diseases as epilepsy, hysteria, and gout."

By the time he had reached his twenty-eighth year he had perfected his education in medicine and returned to his home in Pergamus. Even at that time he had acquired considerable fame as a surgeon, and his fellow-citizens showed their confidence in his ability by choosing him as surgeon to the wounded gladiators shortly after his return to his native city. In these duties his knowledge of anatomy aided him greatly, and he is said to have healed certain kinds of wounds that had previously baffled the surgeons.

In the time of Galen dissections of the human body were forbidden by law, and he was obliged to confine himself to dissections of the lower animals. He had the advantage, however, of the anatomical works of Herophilus and Erasistratus, and he must have depended upon them in perfecting his comparison between the anatomy of men and the lower animals. It is possible that he did make human dissections surreptitiously, but of this we have no proof.

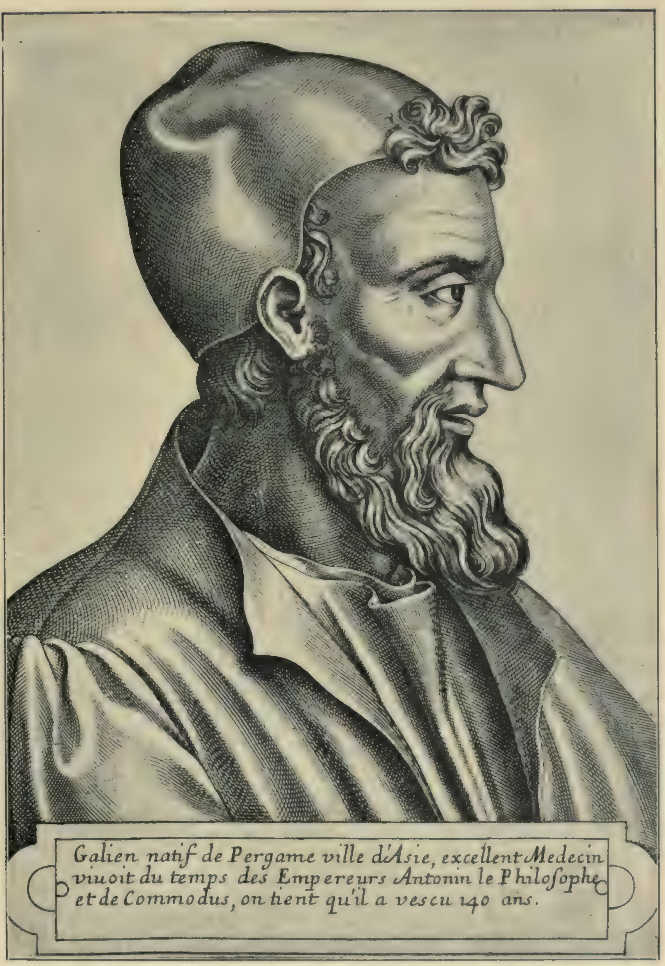
He was familiar with the complicated structure of the bones of the cranium. He described the vertebræ clearly, divided them into groups, and named them after the manner of anatomists of to-day. He was less accurate in his description of the muscles, although a large number of these were described by him. Like all anatomists before the time of Harvey, he had a very erroneous conception of the circulation, although he understood that the heart was an organ for the propulsion of blood, and he showed that the arteries of the living animals did not contain air alone, as was taught by many anatomists. He knew, also, that the heart was made up of layers of fibres that ran in certain fixed directions—that is, longitudinal, transverse, and oblique; but he did not recognize the heart as a muscular organ. In proof of this he pointed out that all muscles require rest, and as the heart did not rest it could not be composed of muscular tissue.

Many of his physiological experiments were conducted upon scientific principles. Thus he proved that certain muscles were under the control of definite sets of nerves by cutting these nerves in living animals, and observing that the muscles supplied by them were rendered useless. He pointed out also that nerves have no power in themselves, but merely conduct impulses to and from the brain and spinal-cord. He turned this peculiar knowledge to account in the case of a celebrated sophist, Pausanias, who had been under the treatment of various physicians for a numbness in the fourth and fifth fingers of his left hand. These physicians had been treating this condition by applications of poultices to the hand itself. Galen, being called in consultation, pointed out that the injury was probably not in the hand itself, but in the *ulner* nerve, which controls sensation in the fourth and fifth fingers. Surmising that the nerve must have been injured in some way, he made careful inquiries of the patient, who recalled that he had been thrown from his chariot some time before, striking and injuring his back. Acting upon this information, Galen applied stimulating remedies to the source of the nerve itself—that is, to the bundle of nerve-trunks known as the brachial plexus, in the shoulder. To the surprise and confusion of his fellow-physicians, this method of treatment proved effective and the patient recovered completely in a short time.

Although the functions of the organs in the chest were not well understood by Galen, he was well acquainted with their anatomy. He knew that the lungs were covered by thin membrane, and that the heart was surrounded by a sac of very similar tissue. He made constant comparisons also between these organs in different animals, as his dissections were performed upon beasts ranging in size from a mouse to an elephant. The minuteness of his observations is shown by the fact that he had noted and described the ring of bone found in the hearts of certain animals, such as the horse, although not found in the human heart or in most animals.

His description of the abdominal organs was in general accurate. He had noted that the abdominal cavity was lined with a peculiar saclike membrane, the peritoneum, which also surrounded most of the organs contained in the cavity, and he made special note that this membrane also enveloped the liver in a peculiar manner. The exactness of the last observation seems the more wonderful when we reflect that even to-day the medical student finds a correct understanding of the position of the folds of the peritoneum one of the most difficult subjects in anatomy.

As a practical physician he was held in the highest esteem by the Romans. The Emperor Marcus Aurelius called him to Rome and appointed him physician-in-ordinary to his son Commodus, and on special occasions Marcus Aurelius himself called in Galen as his medical adviser. On one occasion, the three army surgeons in attendance upon the emperor declared that he was about to be attacked by a fever. Galen relates how "on special command I felt his pulse, and finding it quite normal, considering his age and the time of day, I declared it was no fever but a digestive disorder, due to the food he had eaten, which must be converted into phlegm before being excreted. Then the emperor repeated three times, 'That's the very thing,' and asked what was to be done. I answered that I usually gave a glass of wine with pepper sprinkled on it, but for you kings we only use the safest remedies, and it will suffice to apply wool soaked in hot nard ointment locally. The emperor ordered the wool, wine, etc., to be brought, and I left the room. His feet were warmed by rubbing with hot hands, and after drinking the peppered wine, he said to Pitholaus (his son's tutor), 'We have only one doctor, and that


Galien natif de Pergame ville d'Asie, excellent Medecin
viuoit du temps des Empereurs Antonin le Philoſophe
et de Commodus, on tient qu'il a vescu 140 ans.

GALEN

(From an old print.)

an honest one,' and went on to describe me as the first of physicians and the only philosopher, for he had tried many before who were not only lovers of money, but also contentious, ambitious, envious, and malignant." [7]

It will be seen from this that Galen had a full appreciation of his own abilities as a physician, but inasmuch as succeeding generations for a thousand years concurred in the alleged statement made by Marcus Aurelius as to his ability, he is perhaps excusable for his open avowal of his belief in his powers. His faith in his accuracy in diagnosis and prognosis was shown when a colleague once said to him, "I have used the prognostics of Hippocrates as well as you. Why can I not prognosticate as well as you?" To this Galen replied, "By God's help I have *never* been deceived in my prognosis." [8] It is probable that this statement was made in the heat of argument, and it is hardly to be supposed that he meant it literally.

His systems of treatment were far in advance of his theories regarding the functions of organs, causes of disease, etc., and some of them are still first principles with physicians. Like Hippocrates, he laid great stress on correct diet, exercise, and reliance upon nature. "Nature is the overseer by whom health is supplied to the sick," he says. "Nature lends her aid on all sides, she decides and cures diseases. No one can be saved unless nature conquers the disease, and no one dies unless nature succumbs."

From the picture thus drawn of Galen as an anatomist and physician, one might infer that he should rank very high as a scientific exponent of medicine, even in comparison with modern physicians. There is, however, another side to the picture. His knowledge of anatomy was certainly very considerable, but many of his deductions and theories as to the functions of organs, the cause of diseases, and his methods of treating them, would be recognized as absurd by a modern school-boy of average intelligence. His greatness must be judged in comparison with ancient, not with modern, scientists. He maintained, for example, that respiration and the pulse-beat were for one and the same purpose—that of the reception of air into the arteries of the body. To him the act of breathing was for the purpose of admitting air into the lungs, whence it found its way into the heart, and from there was distributed throughout the body by means of the arteries. The skin also played an important part in supplying the body with air, the pores absorbing the air and distributing it through the arteries. But, as we know that he was aware of the fact that the arteries also contained blood, he must have believed that these vessels contained a mixture of the two.

Modern anatomists know that the heart is divided into two approximately equal parts by an impermeable septum of tough fibres. Yet, Galen, who dissected the hearts of a vast number of the lower animals according to his own account, maintained that this septum was permeable, and that the air, entering one side of the heart from the lungs, passed through it into the opposite side and was then transferred to the arteries.

He was equally at fault, although perhaps more excusably so, in his explanation of the action of the nerves. He had rightly pointed out that nerves were merely connections between the brain and spinal-cord and distant muscles and organs, and had recognized that there were two kinds of nerves, but his explanation of the action of these nerves was that "nervous spirits" were carried to the cavities of the brain by blood-vessels, and from there transmitted through the body along the nerve-trunks.

In the human skull, overlying the nasal cavity, there are two thin plates of bone perforated with numerous small apertures. These apertures allow the passage of numerous nerve-filaments which extend from a group of cells in the brain to the delicate membranes in the nasal cavity. These perforations in the bone, therefore, are simply to allow the passage of the nerves. But Galen gave a very different explanation. He believed that impure "animal spirits" were carried to the cavities of the brain by the arteries in the neck and from there were sifted out through these perforated bones, and so expelled from the body.

He had observed that the skin played an important part in cooling the body, but he seems to have believed that the heart was equally active in overheating it. The skin, therefore, absorbed air for the purpose of "cooling the heart," and this cooling process was aided by the brain, whose secretions aided also in the cooling process. The heart itself was the seat of courage; the brain the seat of the rational soul; and the liver the seat of love.

The greatness of Galen's teachings lay in his knowledge of anatomy of the organs; his weakness was in his interpretations of their functions. Unfortunately, succeeding generations of physicians for something like a thousand years rejected the former but clung to the latter, so that the advances he had made were completely overshadowed by the mistakes of his teachings.

X

A RETROSPECTIVE GLANCE AT CLASSICAL SCIENCE

IT is a favorite tenet of the modern historian that history is a continuous stream. The contention has fullest warrant. Sharp lines of demarcation are an evidence of man's analytical propensity rather than the work of nature. Nevertheless it would be absurd to deny that the stream of history presents an ever-varying current. There are times when it seems to rush rapidly on; times when it spreads out into a broad—seemingly static—current; times when its catastrophic changes remind us of nothing but a gigantic cataract. Rapids and whirlpools, broad estuaries and tumultuous cataracts are indeed part of the same stream, but they are parts that vary one from another in their salient features in such a way as to force the mind to classify them as things apart and give them individual names.

So it is with the stream of history; however strongly we insist on its continuity we are none the less forced to recognize its periodicity. It may not be desirable to fix on specific dates as turning-points to the extent that our predecessors were wont to do. We may not, for example, be disposed to admit that the Roman Empire came to any such cataclysmic finish as the year 476 A.D., when cited in connection with the overthrow of the last Roman Empire of the West, might seem to indicate. But, on the other hand, no student of the period can fail to realize that a great change came over the aspect of the historical stream towards the close of the Roman epoch.

The span from Thales to Galen has compassed about eight hundred years — let us say thirty generations. Throughout this period there is scarcely a generation that has not produced great scientific thinkers—men who have put their mark upon the progress of civilization; but we shall see, as we look forward for a corresponding period, that the ensuing thirty generations produced scarcely a single scientific thinker of the first rank. Eight hundred years of intellectual activity — thirty generations of greatness; then eight hundred years of stasis—thirty generations of mediocrity; such seems to be the record as viewed in perspective. Doubtless it seemed far different to the contemporary observer; it is only in reasonable perspective that any scene can be viewed fairly. But for us, looking back without prejudice across the stage of years, it seems indisputable that a great epoch came to a close at about the time when the barbarian nations of Europe began to sweep down into Greece and Italy. We are forced to feel that we have reached the limits of progress of what historians are pleased to call the ancient world. For about eight hundred years Greek thought has been dominant, but in the ensuing period it is to play a quite subordinate part, except in so far as it influences the thought of an alien race. As we leave this classical epoch, then, we may well recapitulate in brief its triumphs. A few words will suffice to summarize a story the details of which have made up our recent chapters.

In the field of cosmology, Greek genius has demonstrated that the earth is spheroidal, that the moon is earthlike in structure and much smaller than our globe, and that the sun is vastly larger and many times more distant than the moon. The actual size of the earth and the angle of its axis with the ecliptic have been measured with approximate accuracy. It has been shown that the sun and moon present inequalities of motion which may be theoretically explained by supposing that the earth is not situated precisely at the centre of their orbits. A system of eccentrics and epicycles has been elaborated which serves to explain the apparent motions of the heavenly bodies in a manner that may be called scientific even though it is based, as we now know, upon a false hypothesis. The true hypothesis, which places the sun at the centre of the planetary system and postulates the orbital and axial motions of our earth in explanation of the motions of the heavenly bodies, has been put forward and ardently championed, but, unfortunately, is not accepted by the dominant thinkers at the close of our epoch. In this regard, therefore, a vast revolutionary work remains for the thinkers of a later period. Moreover, such observations as the precession of the equinoxes and the moon's evection are as yet unexplained, and measurements of the earth's size, and of the sun's size and distance, are so crude and imperfect as to be in one case only an approximation, and in the other an absurdly inadequate suggestion. But with all these defects, the total achievement of the Greek astronomers is stupendous. To have clearly grasped the idea that the earth is round is in itself an achievement that marks off the classical from the Oriental period as by a great gulf.

In the physical sciences we have seen at least the beginnings of great things. Dynamics and hydrostatics may now, for the first time, claim a place among the sciences. Geometry has been perfected and trigonometry has made a sure beginning. The conception that there are four elementary substances, earth, water, air, and fire, may not appear a secure foundation for chemistry, yet it marks at least an attempt in the right direction. Similarly, the conception that all matter is made up of indivisible particles and that these have adjusted themselves and are perhaps held in place by a whirling motion, while it is scarcely more than a scientific dream, is, after all, a dream of marvellous insight.

In the field of biological science progress has not been so marked, yet the elaborate garnering of facts regarding anatomy, physiology, and the zoological sciences is at least a valuable preparation for the generalizations of a later time.

If with a map before us we glance at the portion of the globe which was known to the workers of the period now in question, bearing in mind at the same time what we have learned as to the seat of labors of the various great scientific thinkers from Thales to Galen, we cannot fail to be struck with a rather startling fact, intimations of which have been given from time to time — the fact, namely, that most of the great Greek thinkers did not live in Greece itself. As our eye falls upon Asia Minor and its outlying islands, we reflect that here were born such men as Thales, Anaximander, Anaximenes, Heraclitus, Pythagoras, Anaxagoras, Socrates, Aristarchus, Hipparchus, Eudoxus, Philolaus, and Galen. From the northern shores of the Ægean came Lucippus, Democritus, and Aristotle. Italy, off to the west, is the home of Pythagoras and Xenophanes in their later years, and of Parmenides and Empedocles, Zeno, and Archimedes. Northern Africa can claim, by birth or by adoption, such names as Euclid, Apollonius of Perga, Herophilus, Erasistratus, Aristippus, Eratosthenes, Ctesibius, Hero, Strabo, and Ptolemy. This is but running over the list of great men whose discoveries have claimed our attention. Were we to extend the list to include a host of workers of the second rank, we should but emphasize the same fact.

All along we are speaking of Greeks, or, as they call themselves, Hellenes, and we mean by these words the people whose home was a small jagged peninsula jutting into the Mediterranean at the southeastern extremity of Europe. We think of this peninsula as the home of Greek culture, yet of all the great thinkers we have just named, not one was born on this peninsula, and perhaps not one in five ever set foot upon it. In point of fact, one Greek thinker of the very first rank, and one only, was born in Greece proper; that one, however, was Plato, perhaps the greatest of them all. With this one brilliant exception (and even he was born of parents who came from the provinces), all the great thinkers of Greece had their origin at the circumference rather than the centre of the empire. And if we reflect that this circumference of the Greek world was in the nature of the case the widely circling region in which the Greek came in contact with other nations, we shall see at once that there could be no more striking illustration in all history than that furnished us here of the value of racial mingling as a stimulus to intellectual progress.

But there is one other feature of the matter that must not be overlooked. Racial mingling gives vitality, but to produce the best effect the mingling must be that of races all of which are at a relatively high plane of civilization. In Asia Minor the Greek mingled with the Semite, who had the heritage of centuries of culture; and in Italy with the Umbrians, Oscans, and Etruscans, who, little as we know of their antecedents, have left us monuments to testify to their high development. The chief reason why the racial mingling of a later day did not avail at once to give new life to Roman thought was that the races which swept down from the north were barbarians. It was no more possible that they should spring to the heights of classical culture than it would, for example, be possible in two or three generations to produce a racer from a stock of draught horses. Evolution does not proceed by such vaults as this would imply. Celt, Goth, Hun, and Slav must undergo progressive development for many generations before the population of northern Europe can catch step with the classical Greek and prepare to march forward. That, perhaps, is one reason why we come to a period of stasis or retrogression when the time of classical activity is over. But, at best, it is only one reason of several.

A RETROSPECTIVE GLANCE

The influence of the barbarian nations will claim further attention as we proceed. But now, for the moment, we must turn our eyes in the other direction and give attention to certain phases of Greek and of Oriental thought which were destined to play a most important part in the development of the Western mind—a more important part, indeed, in the early mediæval period than that played by those important inductions of science which have chiefly claimed our attention in recent chapters. The subject in question is the old familiar one of false inductions or pseudo-science. In dealing with the early development of thought and with Oriental science, we had occasion to emphasize the fact that such false inductions led everywhere to the prevalence of superstition. In dealing with Greek science, we have largely ignored this subject, confining attention chiefly to the progressive phases of thought; but it must not be inferred from this that Greek science, with all its secure inductions, was entirely free from superstition. On the contrary, the most casual acquaintance with Greek literature would suffice to show the incorrectness of such a supposition. True, the great thinkers of Greece were probably freer from this thraldom of false inductions than any of their predecessors. Even at a very early day such men as Xenophanes, Empedocles, Anaxagoras, and Plato attained to a singularly rationalistic conception of the universe.

We saw that "the father of medicine," Hippocrates, banished demonology and conceived disease as due to natural causes. At a slightly later day the sophists challenged all knowledge, and Pyrrhonism became a synonym for scepticism in recognition of the leadership of a master doubter. The entire school of Alexandrians must have been relatively free from superstition, else they could not have reasoned with such effective logicality from their observations of nature. It is almost inconceivable that men like Euclid and Archimedes, and Aristarchus and Eratosthenes, and Hipparchus and Hero, could have been the victims of such illusions regarding occult forces of nature as were constantly postulated by Oriental science. Herophilus and Erasistratus and Galen would hardly have pursued their anatomical studies with equanimity had they believed that ghostly apparitions watched over living and dead alike, and exercised at will a malign influence.

Doubtless the Egyptian of the period considered the work of the Ptolemaic anatomists an unspeakable profanation, and, indeed, it was nothing less than revolutionary — so revolutionary that it could not be sustained in subsequent generations. We have seen that the great Galen, at Rome, five centuries after the time of Herophilus, was prohibited from dissecting the human subject. The fact speaks volumes for the attitude of the Roman mind towards science. Vast audiences made up of every stratum of society thronged the amphitheatre, and watched exultingly while man slew his fellow-man in single or in multiple combat. Shouts of frenzied joy burst from a hundred thousand throats when the death-stroke was given to a new victim. The bodies of the slain, by scores, even by hundreds, were dragged ruthlessly from the arena and hurled into a ditch as contemptuously as if pity were yet unborn and human life the merest bauble. Yet the same eyes that witnessed these scenes with ecstatic approval would have been averted in pious horror had an anatomist dared to approach one of the mutilated bodies with the scalpel of science. It was sport to see the blade of the gladiator enter the quivering, living flesh of his fellow-gladiator; it was joy to see the warm blood spurt forth from the writhing victim while he still lived; but it were sacrilegious to approach that body with the knife of the anatomist, once it had ceased to pulsate with life. Life itself was held utterly in contempt, but about the realm of death hovered the threatening ghosts of superstition. And such, be it understood, was the attitude of the Roman populace in the early and the most brilliant epoch of the empire, before the Western world came under the influence of that Oriental philosophy which was presently to encompass it.

In this regard the Alexandrian world was, as just intimated, far more advanced than the Roman, yet even there we must suppose that the leaders of thought were widely at variance with the popular conceptions. A few illustrations, drawn from Greek literature at various ages, will suggest the popular attitude. In the first instance, consider the poems of Homer and of Hesiod. For these writers, and doubtless for the vast majority of their readers, not merely of their own but of many subsequent generations, the world is peopled with a multitude of invisible apparitions, which, under title of gods, are held to dominate the affairs of man. It is sometimes difficult to discriminate as to where the Greek imagination drew the line between fact and allegory; nor need we attempt to analyse the early poetic narratives to this end. It will better serve our present purpose to cite three or four instances which illustrate the tangibility of beliefs based upon pseudo-scientific inductions.

Let us cite, for example, the account which Herodotus gives us of the actions of the Greeks at Platæa, when their army confronted the remnant of the army of Xerxes, in the year 479 B.C. Here we see each side hesitating to attack the other, merely because the oracle had declared that whichever side struck the first blow would lose the conflict. Even after the Persian soldiers, who seemingly were a jot less superstitious or a shade more impatient than their opponents, had begun the attack, we are told that the Greeks dared not respond at first, though they were falling before the javelins of the enemy, because, forsooth, the entrails of a fowl did not present an auspicious appearance. And these were Greeks of the same generation with Empedocles and Anaxagoras and Æschylus; of the same epoch with Pericles and Sophocles and Euripides and Phidias. Such was the scientific status of the average mind—nay, of the best minds—with here and there a rare exception, in the golden age of Grecian culture.

Were we to follow down the pages of Greek history, we should but repeat the same story over and over. We should, for example, see Alexander the Great balked at the banks of the Hyphasis, and forced to turn back because of inauspicious auguries based as before upon the dissection of a fowl. Alexander himself, to be sure, would have scorned the augury; had he been the prey of such petty superstitions he would never have conquered Asia. We know how he compelled the oracle at Delphi to yield to his wishes; how he cut the Gordian knot; how he made his dominating personality felt at the temple of Ammon in Egypt. We know, in a word, that he yielded to superstitions only in so far as they served his purpose. Left to his own devices, he would not have consulted an oracle at the banks of the Hyphasis; or, consulting, would have forced from the oracle a favorable answer. But his subordinates were mutinous and he had no choice. Suffice it for our present purpose that the oracle was consulted, and that its answer turned the conqueror back.

One or two instances from Roman history may complete the picture. Passing over all those mythical narratives which virtually constitute the early history of Rome, as preserved to us by such historians as Livy and Dionysius, we find so logical an historian as Tacitus recording a miraculous achievement of Vespasian without adverse comment. "During the months when Vespasian was waiting at Alexandria for the periodical season of the summer winds, and a safe navigation, many miracles occurred by which the favor of Heaven and a sort of bias in the powers above towards Vespasian were manifested." Tacitus then describes in detail the cure of various maladies by the emperor, and relates that the emperor on visiting a temple was met there, in the spirit, by a prominent Egyptian who was proved to be at the same time some eighty miles distant from Alexandria.

It must be admitted that Tacitus, in relating that Vespasian caused the blind to see and the lame to walk, qualifies his narrative by asserting that "persons who are present attest the truth of the transaction when there is nothing to be gained by falsehood." Nor must we overlook the fact that a similar belief in the power of royalty has persisted almost to our own day. But no such savor of scepticism attaches to a narrative which Dion Cassius gives us of an incident in the life of Marcus Aurelius—an incident that has become famous as the episode of The Thundering Legion. Xiphilinus has preserved the account of Dion, adding certain picturesque interpretations of his own. The original narrative, as cited, asserts that during one of the northern campaigns of Marcus Aurelius, the emperor and his army were surrounded by the hostile Quadi, who had every advantage of position and who presently ceased hostilities in the hope that heat and thirst would deliver their adversaries into their hands without the trouble of further fighting. "Now," says Dion, "while the Romans, unable either to combat or to retreat, and reduced to the last extremity by wounds, fatigue, heat, and thirst, were standing helplessly at their posts, clouds suddenly gathered in great number and rain descended in floods—certainly not without divine intervention, since the Egyptian Maege Arnulphis, who was with Marcus Antoninus, is said to have invoked several genii by the aerial mercury by enchantment, and thus through them had brought down rain."

Here, it will be observed, a supernatural explanation is given of a natural phenomenon. But the narrator does not stop with this. If we are to accept the account of Xiphilinus, Dion brings forward some striking proofs of divine interference. Xiphilinus gives these proofs in the following remarkable paragraph:

"Dion adds that when the rain began to fall every soldier lifted his head towards heaven to receive the water in his mouth; but afterwards others held out their shields or their helmets to catch the water for themselves and for their horses. Being set upon by the barbarians . . . while occupied in drinking, they would have been seriously incommoded had not heavy hail and numerous thunderbolts thrown consternation into the ranks of the enemy. Fire and water were seen to mingle as they left the heavens. The fire, however, did not reach the Romans, but if it did by chance touch one of them it was immediately extinguished, while at the same time the rain, instead of comforting the barbarians, seemed merely to excite like oil the fire with which they were being consumed. Some barbarians inflicted wounds upon themselves as though their blood had power to extinguish flames, while many rushed over to the side of the Romans, hoping that there water might save them."

We cannot better complete these illustrations of pagan credulity than by adding the comment of Xiphilinus himself. That writer was a Christian, living some generations later than Dion. He never thought of questioning the facts, but he felt that Dion's interpretation of these facts must not go unchallenged. As he interprets the matter, it was no pagan magician that wrought the miracle. He even inclines to the belief that Dion himself was aware that Christian interference, and not that of an Egyptian, saved the day. "Dion knew," he declares, "that there existed a legion called The Thundering Legion, which name was given it for no other reason than for what came to pass in this war," and that this legion was composed of soldiers from Militene who were all professed Christians. "During the battle," continues Xiphilinus, "the chief of the Pretonians had set at Marcus Antoninus, who was in great perplexity at the turn events were taking, representing to him that there was nothing the people called Christians could not obtain by their prayers, and that among his forces was a troop composed wholly of followers of that religion. Rejoiced at this news, Marcus Antoninus demanded of these soldiers that they should pray to their god, who granted their petition on the instant, sent lightning among the enemy and consoled the Romans with rain. Struck by this wonderful success, the emperor honored the Christians in an edict and named their legion The Thundering. It is even asserted that a letter existed by Marcus Antoninus on this subject. The pagans well knew that the company was called The Thunderers, having attested the fact themselves, but they revealed nothing of the occasion on which the leader received the name."[1]

Peculiar interest attaches to this narrative as illustrating both credulousness as to matters of fact and pseudo-scientific explanation of alleged facts. The modern interpreter may suppose that a violent thunderstorm came up during the course of a battle between the Romans and the so-called barbarians, and that owing to the local character of the storm, or a chance discharge of lightning, the barbarians suffered more than their opponents. We may well question whether the philosophical emperor himself put any other interpretation than this upon the incident. But, on the other hand, we need not doubt that the major part of his soldiers would very readily accept such an explanation as that given by Dion Cassius, just as most readers of a few centuries later would accept the explanation of Xiphilinus. It is well to bear this thought in mind in considering the static period of science upon which we are entering. We shall perhaps best understand this period, and its seeming retrogressions, if we suppose that the average man of the Middle Ages was no more credulous, no more superstitious, than the average Roman of an earlier period or than the average Greek; though the precise complexion of his credulity had changed under the influence of Oriental ideas, as we have just seen illustrated by the narrative of Xiphilinus.

APPENDIX

REFERENCE-LIST, NOTES, AND BIBLIOGRAPHIES

CHAPTER I

PREHISTORIC SCIENCE

Length of the Prehistoric Period.—It is of course quite impossible to reduce the prehistoric period to any definite number of years. There are, however, numerous bits of evidence that enable an anthropologist to make rough estimates as to the relative lengths of the different periods into which prehistoric time is divided. Gabriel de Mortillet, one of the most industrious students of prehistoric archæology, ventured to give a tentative estimate as to the numbers of years involved in each period. He of course claimed for this nothing more than the value of a scientific guess. It is, however, a guess based on a very careful study of all data at present available. Mortillet divides the prehistoric period, as a whole, into four epochs. The first of these is the preglacial, which he estimates as comprising seventy-eight thousand years; the second is the glacial, covering one hundred thousand years; then follows what he terms the Solutréen, which numbers eleven thousand years; and, finally, the Magdalénien, comprising thirty-three thousand years. This gives, for the prehistoric period proper, a term of about two hundred and twenty-two thousand years. Add to this perhaps twelve thousand years ushering in the civilization of Egypt, and the six thousand years of stable, sure chronology of the historical period, and we have something like two hundred and thirty thousand or two hundred and forty thousand years as the age of man.

"These figures," says Mortillet, "are certainly not exaggerated. It is even probable that they are below the truth. Constantly new discoveries are being made that tend to remove farther back the date of man's appearance." We see, then, according to this estimate, that about a quarter of a million years have elapsed since man evolved to a state that could properly be called human. This guess is as good as another, and it may advantageously be kept in mind, as it will enable us all along to understand better than we might otherwise be able to do the tremendous force of certain prejudices and preconceptions which recent man inherited from his prehistoric ancestor. Ideas which had passed current as unquestioned truths for one hundred thousand years or so are not easily cast aside.

In going back, in imagination, to the beginning of the prehistoric period, we must of course reflect, in accordance with modern ideas on the subject, that there was no year, no millennium even, when it could be said expressly: "This being was hitherto a primate, he is now a man." The transition period must have been enormously long, and the changes from generation to generation, even from century to century, must have been very slight. In speaking of the extent of the age of man this must be borne in mind: it must be recalled that, even if the period were not vague for other reasons, the vagueness of its beginning must make it indeterminate.

Bibliographical Notes.—A great mass of literature has been produced in recent years dealing with various phases of the history of prehistoric man. No single work known to the writer deals comprehensively with the scientific attainments of early man; indeed, the subject is usually ignored, except where practical phases of the mechanical arts are in question. But of course any attempt to consider the condition of primitive man takes into account, by inference at least, his knowledge and attainments. Therefore, most works on anthropology, ethnology, and primitive culture may be expected to throw some light on our present subject. Works dealing with the social and mental conditions of existing savages are also of importance, since it is now an accepted belief that the ancestors of civilized races evolved along similar lines and passed through corresponding stages of nascent culture. Herbert

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Spencer's *Descriptive Sociology* presents an unequalled mass of facts regarding existing primitive races, but, unfortunately, its inartistic method of arrangement makes it repellent to the general reader. E. B. Tyler's *Primitive Culture* and *Anthropology;* Lord Avebury's *Prehistoric Times*, *The Origin of Civilization*, and *The Primitive Condition of Man;* W. Boyd Dawkin's *Cave-Hunting* and *Early Man in Britain;* and Edward Clodd's *Childhood of the World* and *Story of Primitive Man* are deservedly popular. Paul Topinard's *Éléments d'Anthropologie Générale* is one of the best-known and most comprehensive French works on the technical phases of anthropology; but Mortillet's *Le Préhistorique* has a more popular interest, owing to its chapters on primitive industries, though this work also contains much that is rather technical. Among periodicals, the *Revue de l'École d'Anthropologie de Paris*, published by the professors, treats of all phases of anthropology; and the *American Anthropologist*, edited by F. W. Hodge for the American Anthropological Association, and intended as "a medium of communication between students of all branches of anthropology," contains much that is of interest from the present stand-point. The last-named journal devotes a good deal of space to Indian languages.

CHAPTER II

EGYPTIAN SCIENCE

[1] (p. 34). Sir J. Norman Lockyer, *The Dawn of Astronomy;* a study of the temple worship and mythology of the ancient Egyptians, London, 1894.

[2] (p. 43). G. Maspero, *Histoire Ancienne des Peuples de l'Orient Classique*, Paris, 1895. Translated as (1) *The Dawn of Civilization*, (2) *The Struggle of the Nations*, (3) *The Passing of the Empires*, 3 vols., London and New York, 1894–1900. Professor Maspero is one of the most famous of living Orientalists. His most important special studies have to do with Egyptology, but his writings cover the entire field of Oriental antiquity. He is a notable stylist, and his works are at once readable and authoritative.

[3] (p. 44). Adolf Erman, *Life in Ancient Egypt*, London,

1894, pp. 352. (Translated from the original German work entitled *Aegypten und aegyptisches Leben in Alterthum*, Tübigen, 1887.) An altogether admirable work, full of interest for the general reader, though based on the most erudite studies.

[4] (p. 47). Erman, *op. cit.*, pp. 356, 357.

[5] (p. 48). Erman, *op. cit.*, p. 357. The work on Egyptian medicine here referred to is Georg Ebers' edition of an Egyptian document discovered by the explorer whose name it bears. It remains the most important source of our knowledge of Egyptian medicine. As mentioned in the text, this document dates from the eighteenth dynasty—that is to say, from about the fifteenth or sixteenth century, B.C., a relatively late period of Egyptian history.

[6] (p. 49). Erman, *op. cit.*, p. 357.

[7] (p. 50). The *History* of Herodotus, II., 85–90. There are numerous translations of the famous work of the "father of history," one of the most recent and authoritative being that of G. C. Macaulay, M.A., in two volumes, Macmillan & Co., London and New York, 1890.

[8] (p. 50). The *Historical Library* of Diodorus the Sicilian, London, 1700. This most famous of ancient world histories is difficult to obtain in an English version. The most recently published translation known to the writer is that of G. Booth, London, 1814.

[9] (p. 51). Erman, *op. cit.*, p. 357.

[10] (p. 52). The Papyrus Rhind is a sort of mathematical hand-book of the ancient Egyptians; it was made in the time of the Hyksos Kings (about 2000 B.C.), but is a copy of an older book. It is now preserved in the British Museum.

The most accessible recent sources of information as to the social conditions of the ancient Egyptians are the works of Maspero and Erman, above mentioned; and the various publications of W. M. Flinders Petrie, *The Pyramids and Temples of Gizeh*, London, 1883; *Tanis I.*, London, 1885; *Tanis II., Nebesheh, and Defennel*, London, 1887; *Ten Years' Diggings*, London, 1892; *Syria and Egypt from the Tel-el-Amarna Letters*, London, 1898, etc. The various works of Professor Petrie, recording his explorations from year to year, give the fullest available insight into Egyptian archæology.

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CHAPTER III

SCIENCE OF BABYLONIA AND ASSYRIA

[1] (p. 57). The Medes. Some difference of opinion exists among historians as to the exact ethnic relations of the conquerors; the precise date of the fall of Nineveh is also in doubt.

[2] (p. 57). Darius. The familiar Hebrew narrative ascribes the first Persian conquest of Babylon to Darius, but inscriptions of Cyrus and of Nabonidus, the Babylonian king, make it certain that Cyrus was the real conqueror. These inscriptions are preserved on cylinders of baked clay, of the type made familiar by the excavation of the past fifty years, and they are invaluable historical documents.

[3] (p. 58). Berosus. The fragments of Berosus have been translated by I. P. Cory, and included in his *Ancient Fragments of Phœnician, Chaldean, Egyptian, and Other Writers*, London, 1826, second edition, 1832.

[4] (p. 58). Chaldean learning. Recent writers reserve the name Chaldean for the later period of Babylonian history—the time when the Greeks came in contact with the Mesopotamians—in contradistinction to the earlier periods which are revealed to us by the archæological records.

[5] (p. 59). King Sargon of Agade. The date given for this early king must not be accepted as absolute; but it is probably approximately correct.

[6] (p. 59). Nippur. See the account of the early expeditions as recorded by the director, Dr. John P. Peters, *Nippur*, or explorations and adventures, etc., New York and London, 1897.

[7]. (p. 62). Fritz Hommel, *Geschichte Babyloniens und Assyriens*, Berlin, 1885.

[8] (p. 63). R. Campbell Thompson, *Reports of the Magicians and Astrologers of Nineveh and Babylon*, London, 1900, p. xix.

[9] (p. 64). George Smith, *The Assyrian Canon*, p. 21.

[10] (p. 64). Thompson, *op. cit.*, p. xix.

[11] (p. 65). Thompson, *op. cit.*, p. 2.

[12] (p. 67). Thompson, *op. cit.*, p. xvi.

[13] (p. 68). Sextus Empiricus, author of *Adversus Mathematicos*, lived about 200 A.D.

[14] (p. 68). R. Campbell Thompson, *op. cit.*, p. xxiv.

[15] (p. 72). *Records of the Past* (editor, Samuel Birch), vol. III., p. 139.

[16] (p. 72). *Ibid.*, vol. V., p. 16.

[17] (p. 72). Quoted in *Records of the Past*, vol. III., p. 143, from the *Translations of the Society of Biblical Archæology*, vol. II., p. 58.

[18] (p. 73). *Records of the Past*, vol. I., p. 131.

[19] (p. 73). *Ibid.*, vol. V., p. 171.

[20] (p. 74). *Ibid.*, vol. V., p. 169.

[21] (p. 74). Joachim Menant, *La Bibliothèque du Palais de Ninive*, Paris, 1880.

[22] (p. 76). Code of Khamurabi. This famous inscription is on a block of black diorite nearly eight feet in height. It was discovered at Susa by the French expedition under M. de Morgan, in December, 1901. We quote the translation given in *The Historians' History of the World*, edited by Henry Smith Williams, London and New York, 1904, vol. I., p. 510.

[23] (p. 77). *The Historical Library* of Diodorus Siculus, vol. I., p. 519.

[24] (p. 82). George S. Goodspeed, Ph.D., *History of the Babylonians and Assyrians*, New York, 1902.

[25] (p. 82). George Rawlinson, *Great Oriental Monarchies* (second edition, London, 1871), vol. III., pp. 75 ff.

Of the books mentioned above, that of Hommel is particularly full in reference to culture development; Goodspeed's small volume gives an excellent condensed account; the original documents as translated in the various volumes of *Records of the Past* are full of interest; and Menant's little book is altogether admirable. The work of excavation is still going on in old Babylonia, and newly discovered texts add from time to time to our knowledge, but A. H. Layard's *Nineveh and its Remains* (London, 1849) still has importance as a record of the most important early discoveries. The general histories of Antiquity of Duncker, Lenormant, Maspero, and Meyer give full treatment of Babylonian and Assyrian development. Special histories of Babylonia and Assyria, in addition to these named above, are Tiele's *Babylonisch-Assyrische Geschichte* (Zwei Tiele, Gotha, 1886–1888); Winckler's *Geschichte Babyloniens und Assyriens* (Berlin, 1885–1888), and Rogers' *History of Babylonia and Assyria*, New York and London, 1900, the last of which, however, deals almost exclusively with political history. Certain phases of science, particularly with reference to chronology and cosmology, are treated by Edward Meyer (*Geschichte des Alterthum*, vol. I., Stuttgart, 1884), and by P. Jensen (*Die Kosmologie der Babylonier*, Strassburg, 1890), but no comprehensive specific treatment of the subject in its entirety has yet been attempted.

CHAPTER IV

THE DEVELOPMENT OF THE ALPHABET

[1] (p. 87). Vicomte E. de Rougé, *Mémoire sur l'Origine Égyptienne de l'Alphabet Phénicien*, Paris, 1874.

[2] (p. 88). See the various publications of Mr. Arthur Evans.

[3] (p. 89). Aztec and Maya writing. These pictographs are still in the main undecipherable, and opinions differ as to the exact stage of development which they represent.

[4] (p. 90). E. A. Wallace Budge's *First Steps in Egyptian*, London, 1895, is an excellent elementary work on the Egyptian writing. Professor Erman's *Egyptian Grammar*, London, 1894, is the work of perhaps the foremost living Egyptologist.

[5] (p. 93). Extant examples of Babylonian and Assyrian writing give opportunity to compare earlier and later systems, so the fact of evolution from the pictorial to the phonetic system rests on something more than mere theory.

[6] (p. 96). Friedrich Delitzsch, *Assyrische Lesestucke mit grammatischen Tabellen und vollständigem Glossar einführung in die assyrische und babylonische Keilschrift-litteratur bis hinauf zu Hammurabi*, Leipzig, 1900.

[7] (p. 97). It does not appear that the Babylonians themselves ever gave up the old system of writing, so long as they retained political autonomy.

[8] (p. 101). See Isaac Taylor's *History of the Alphabet; an Account of the Origin and Development of Letters*, new edition, 2 vols., London, 1899.

For fac-similes of the various scripts, see Henry Smith Williams' *History of the Art of Writing*, 4 vols, New York and London, 1902–1903.

CHAPTER V

THE BEGINNINGS OF GREEK SCIENCE

[1] (p. 111). Anaximander, as recorded by Plutarch, Symp. VIII., 730E. See Arthur Fairbanks' *First Philosophers of Greece: an Edition and Translation of the Remaining Fragments of the Pre-Socratic Philosophers, together with a Translation of the more Important Accounts of their Opinions Contained in the Early Epitomes of their Works*, London, 1898. This highly scholarly and extremely useful book contains the Greek text as well as translations.

CHAPTER VI

THE EARLY GREEK PHILOSOPHERS IN ITALY

[1] (p. 117). George Henry Lewes, *A Biographical History of Philosophy from its Origin in Greece down to the Present Day*, enlarged edition, New York, 1888, p. 17.

[2] (p. 121). Diogenes Laertius, *The Lives and Opinions of Eminent Philosophers*, C. D. Yonge's translation, London, 1853, VIII., 15.

[3] (p. 121). Alexander, *Successions of Philosophers*.

[4] (p. 122). "All over its centre." Presumably this is intended to refer to the entire equatorial region.

[5] (p. 125). Laertius, *op. cit.*, pp. 348–351.

[6] (p. 128). Arthur Fairbanks, *The First Philosophers of Greece*, London, 1898, pp. 67–71.

[7] (p. 129). *Ibid.*, p. 83.

[8] (p. 130). *Ibid.*, p. 109.

[9] (p. 131). Heinrich Ritter, *The History of Ancient Philosophy*, translated from the German by A. J. W. Morrison, 4 vols., London, 1838, vol, I., p. 463.

[10] (p. 131). *Ibid.*, p. 465.

[11] (p. 132). George Henry Lewes, *op. cit.*, p. 51.

[12] (p. 135). Fairbanks, *op. cit.*, p. 201.

[13] (p. 136). *Ibid.*, p. 234.

[14] (p. 137). *Ibid.*, p. 189.

[15] (p. 137). *Ibid.*, p. 220.

[16] (p. 138). *Ibid.*, p. 189.

[17] (p. 138). *Ibid.*, p. 191.

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CHAPTER VII

GREEK SCIENCE IN THE EARLY ATTIC PERIOD

[1] (p. 150). Theodor Gomperz, *Greek Thinkers: a History of Ancient Philosophy* (translated from the German by Laurie Magnes), New York, 1901, pp. 220, 221.

[1] (p. 153). Aristotle's *Treatise on Respiration*, ch. ii.

[3] (p. 159). Fairbanks' translation of the fragments of Anaxagoras, in *The First Philosophers of Greece*, pp. 239–243.

CHAPTER VIII

POST-SOCRATIC SCIENCE AT ATHENS

[1] (p. 180). Alfred William Benn, *The Philosophy of Greece Considered in Relation to the Character and History of its People*, London, 1898, p. 186.

[2] (p. 183). Aristotle, quoted in William Whewell's *History of the Inductive Sciences* (second edition, London, 1847), vol. II., p. 161.

CHAPTER IX

GREEK SCIENCE OF THE ALEXANDRIAN OR HELLENISTIC PERIOD

[1] (p. 195). Tertullian's *Apologeticus*.

[2] (p. 205). We quote the quaint old translation of North, printed in 1657.

CHAPTER X

SCIENCE OF THE ROMAN PERIOD

[1] (p. 258). *The Geography of Strabo*, translated by H. C. Hamilton and W. Falconer, 3 vols. London, 1857, vol. I., pp. 19, 20.

[2] (p. 260). *Ibid.*, p. 154.

[3] (p. 263). *Ibid.*, pp. 169, 170.

[4] (p. 264). *Ibid.*, pp. 166, 167.

[5] (p. 271). K. O. Miller and John W. Donaldson, *The History of the Literature of Greece*, 3 vols., London, vol. III., p. 268.

[6] (p. 276). E. T. Withington, *Medical History from the Earliest Times*, London, 1894, p. 118.

[7] (p. 281). *Ibid.*

[8] (p. 281). Johann Hermann Bass, *History of Medicine*, New York, 1889.

CHAPTER XI

A RETROSPECTIVE GLANCE AT CLASSICAL SCIENCE

[1] (p. 298). Dion Cassius, as preserved by Xiphilinus. Our extract is quoted from the translation given in *The Historians' History of the World* (edited by Henry Smith Williams), 25 vols., London and New York, 1904, vol. VI., p. 297 ff.

[For further bibliographical notes, the reader is referred to the Appendix of volume V.]

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